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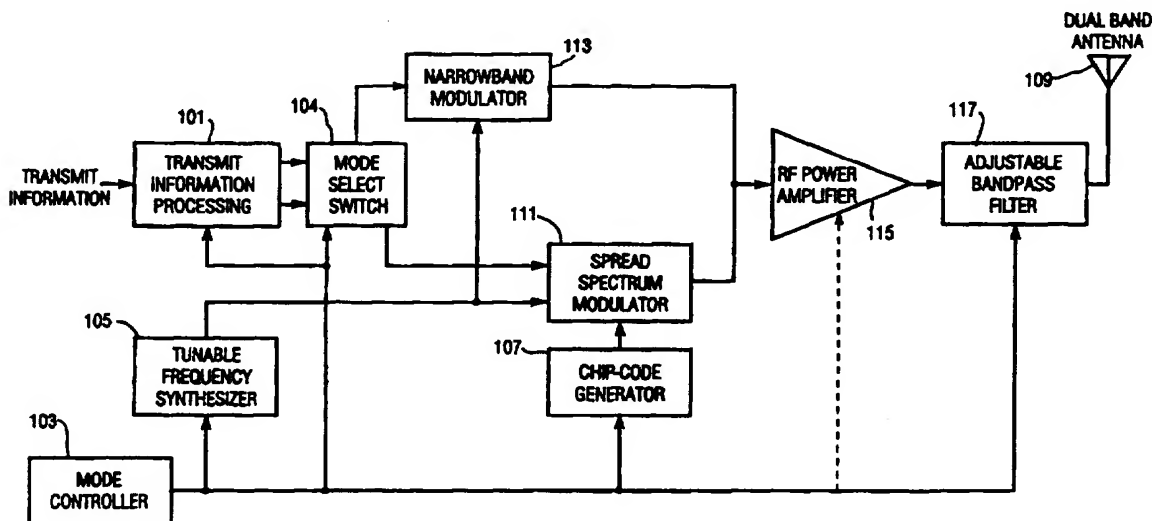
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(54) Title: MULTI-BAND, MULTI-MODE SPREAD-SPECTRUM COMMUNICATION SYSTEM



(57) Abstract

A technique for spread-spectrum communication (figs. 1, 3, 12 and 14) which uses more than one mode and more than one frequency band. Selectable modes include narrowband mode (113) and spread-spectrum mode (111), or cellular mode and microcellular mode. Selectable frequency bands include both licensed and unlicensed frequency bands, particularly frequency bands including the 902-928 MHz, 1850-1990 MHz, and 2.4-2.4835 GHz frequency bands. Spread-spectrum communication channels are 10 MHz or less in width. The frequency band onto which spread-spectrum signals are encoded may be changed upon a change in environment or other control trigger, such as establishment or deestablishment of communication with a private access network. A multi-band transmitter (fig. 12) comprises a single frequency synthesizer and a frequency source (606) (e.g., a local oscillator), coupled to a selectable band pass filter (619, 620). A multi-band receiver (fig. 14) capable of monitoring one or more frequency bands comprises bank of bandpass filters (714, 715) and a demodulator comprising a single frequency synthesizer and a frequency source (721).

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S P E C I F I C A T I O NMULTI-BAND, MULTI-MODE SPREAD-SPECTRUM
COMMUNICATION SYSTEM

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CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of copending U.S. application Serial No. 08/293,671 filed on August 18, 1994 entitled "MULTI-BAND, MULTI-MODE SPREAD-SPECTRUM COMMUNICATION SYSTEM," which is a continuation-in-part of: (a) U.S. application Serial No. 08/146,492 filed on November 1, 1993 entitled "DUAL-MODE WIRELESS UNIT WITH TWO SPREAD-SPECTRUM FREQUENCY BANDS," which corresponds to international application Serial No. PCT/US94/12464; (b) U.S. application Serial No. 08/059,021 filed May 4, 1993, entitled "DUAL-BAND SPREAD-SPECTRUM COMMUNICATION" (which is a continuation-in-part of Serial No. 07/976,700 filed November 16, 1992 entitled "SPREAD-SPECTRUM USING TEN-MEGAHERTZ CHANNELIZATION", which corresponds to international application Ser. No. PCT/US93/11065); and (c) U.S. application Serial No. 08/206,045 filed on March 1, 1994, entitled "DUAL-MODE TRANSMITTER AND RECEIVER" (which is a continuation of Serial No. 07/948,293 filed on September 18, 1992, entitled "DUAL-MODE TRANSMITTER AND RECEIVER" and now issued as U.S. Patent No. 5,291,516, which is a file-wrapper continuation of Serial No. 07/698,694 filed May 13, 1991, also bearing the same title).

BACKGROUND OF THE INVENTION

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1. Field of the Invention

This invention relates to spread-spectrum communication and, more particularly, to a communication system using multiple communication modes over multiple frequency bands.

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2. Description of Related Art

Cellular telephony has been well known for many years, but with its growing popularity, more channels in the allocated cellular frequencies have become necessary. Among the proposed advances in the art have been a move from frequency division multiple access (FDMA) systems using narrowband analog communication to digital voice communication using traditional narrowband FDMA techniques possibly coupled with time division multiple access (TDMA) techniques. Further proposed advances include the use of code division multiple access (CDMA) techniques such as spread spectrum systems. Examples of communication protocols include IS-45, IS-95, DCS1900 (otherwise known as GSM), DECT (Digital European Cordless Telephone), and AMPS.

Another approach to the problem of allowing increased numbers of users in a geographic location is the concept of personal communications systems, or PCN's, which utilize microcells. A microcell is similar to a cell in a traditional cellular system, except much smaller. Where a traditional cell may cover an area of several square miles, a microcell may only be a few hundred feet in diameter. By limiting transmit power, more microcells, and thus more users, may be co-located in a geographic area.

Prior art does not teach a method for operation of a single telephone which has the ability to function both as a narrowband frequency, time, and/or code division multiplexed cellular phone, as well as a microcellular telephone utilizing time, frequency, or code division multiplexing, where the cellular and microcellular functions either share the same frequency bands of operation or are offset from each other. Nor does the prior art teach such a system where the microcellular mode may employ a paging unit independent of the unit's telephone functionality.

For purposes of the present specification, "analog voice" is described as a system where an analog voice system directly modulates a radio frequency (RF) carrier or intermediate frequency (IF) signal, and digital voice is
5 described as a system where the signal is first digitized, and possibly compressed through any number of methods common and well known in the art, and whose digital signal is then used for RF carrier or IF modulation. A narrow band modulation typically uses amplitude modulation (AM) or frequency
10 modulation (FM), and has a bandwidth between 3 kHz and 30 kHz.

In spread-spectrum communication, the spread-spectrum signal which is generated and transmitted has a spreading bandwidth which exceeds the bandwidth of the data
15 stream. When using spread-spectrum techniques for wireless communication, it may be necessary to avoid or minimize interference with other users of the electromagnetic spectrum. Some examples of such other users are microwave communication users (such as the Operational Fixed Services ("OFS") using
20 microwave communication towers) and cellular communication users (such as those using cellular telephones). In particular, OFS services are critical to controlling, among other things, the nation's electric power grid, which makes the possibility of inadvertent OFS disruption extremely
25 serious. Accordingly, it would be advantageous to avoid or minimize interference with microwave and cellular communication users.

In wireless communication, the transmitted signal
30 may be subject to various forms of frequency-selective fading, which may cause the signal to fade or drop out over a localized range of frequencies. Although spread-spectrum signals are distributed over a wider range of frequencies than narrowband signals, they may also be subject to frequency-
35 selective fading over a portion of their spreading bandwidth. Accordingly, it would be advantageous to mitigate the effect of frequency-selective fading.

Spread-spectrum modulation in more than one frequency band can be difficult due to the wide separation between frequency bands. For example, operation in the 900 megahertz and 1800 megahertz bands could require a synthesizer capable of covering approximately 1,000 megahertz in frequency spectrum. However, in hand-held equipment such as telephones, it is undesirable to use more than one synthesizer, or even more than one oscillator, due to increased cost, weight, and related considerations. Accordingly, it would be advantageous to provide a spread-spectrum system in which a single, relatively narrow, synthesizer would serve more than one operating frequency band.

SUMMARY OF THE INVENTION

The invention provides in one aspect a transmitter and receiver capable of operating in a plurality of frequency bands and/or in a plurality of modes, making use of either narrowband or spread-spectrum communication techniques. The invention may be embodied as a cellular or cordless telephone which utilizes frequency division multiplexing, time division multiplexing, code division multiplexing, or various combinations thereof. In one embodiment, the invention possesses both cellular and microcellular functionality, wherein transmission and/or reception may occur using either narrowband or spread-spectrum signals in conjunction with either FDMA, TDMA, or CDMA techniques, or any combination thereof. A system in accordance with the present invention may have two or more modes, such as a cellular mode and a microcellular mode, or such as a spread-spectrum mode and a narrowband mode, and the various modes may occupy common frequency bands, overlapping frequency bands, or distinct, offset frequency bands.

Another aspect of the invention provides a technique for spread-spectrum communication which reduces interference from microwave and cellular communication users, especially when transmitting in a communication band generally used by

those users. In particular, said embodiment provides a spread-spectrum technique having a spreading bandwidth of about 10 MHz or less, in combination with a known center frequency. The known center frequency may be within a
5 microwave communication band or a cellular communication band.

Another aspect of the invention provides a technique for spread-spectrum communication which uses more than one frequency band, particularly unlicensed frequency bands,
10 including the 902--928 MHz, 1850--1990 MHz, and 2.4--2.4835 GHz frequency bands, and including the 1910--1930 MHz frequency band or other future unlicensed frequency bands. In said embodiment, the frequency band onto which spread-spectrum signals are encoded may be changed upon a change in
15 environment or other control trigger, such as establishment or de-establishment of communication with a private access network.

The invention may be embodied as a transmitter
20 generally comprising a switch, a tunable-frequency synthesizer, one or more modulators, a dual-band power amplifier (where the dual modes occupy distinct frequency bands) or a single-band power amplifier (where the dual modes occupy single, contiguous, or closely placed distinct bands),
25 and an adjustable bandpass filter. The switch may be used to select either narrowband or spread-spectrum modulation, or may be used to select one of a plurality of frequency bands for transmission. If narrowband mode is selected, a narrowband modulator modulates an input signal, combines it with a
30 carrier frequency generated by the tunable frequency synthesizer, and provides an output to the power amplifier and the adjustable bandpass filter for transmission. If spread-spectrum mode is selected, the input signal is provided to a spread-spectrum modulator for generating a spread-spectrum
35 signal. The spread-spectrum signal is combined with a carrier frequency generated by the tunable frequency synthesizer and provided to the power amplifier and the adjustable bandpass

filter for transmission. The adjustable bandpass filter may be tuned, and the power amplifier switched, where distinct, offset frequencies are employed for the two operating modes.

5 The invention may also be embodied as a receiver generally comprising a switch, a tunable-frequency synthesizer, a tunable bandpass filter, a preamplifier, a frequency converter, an IF amplifier, and one or more demodulators. The receiver generally operates in reverse
10 fashion from the transmitter, whereby the mode select switch is used to select between narrowband or spread-spectrum reception. If in narrowband mode, the adjustable bandpass filter may be adjusted to a narrow bandwidth for passing a received narrowband signal, while in a spread-spectrum mode
15 the adjustable bandpass filter may be adjusted to a wide bandwidth for passing a received spread-spectrum signal. The bandpass filter also is tunable, where different frequencies are utilized for distinct modes, and the preamplifier may also be switch selected or tuned to the appropriate band where the
20 dual modes employ distinct, separated frequency band. The received signal is converted to an IF signal using a local oscillator signal from the tunable-frequency synthesizer, and the IF signal is demodulated by either the spread-spectrum demodulator or the narrowband demodulator depending on the
25 chosen mode.

 The invention further provides in another aspect a dual-band spread-spectrum modulator which uses a single, relatively narrow, synthesizer to serve two operating
30 frequency bands. In the lower frequency band, the synthesizer may operate in a high-side injection mode, while in the higher frequency range, the synthesizer may operate in a low-side injection mode. In one embodiment, the lower frequency range may comprise about 1850 to 1990 megahertz, while the higher
35 frequency range may comprise about 2400 to 2483.5 megahertz.

Additional objects and advantages of the invention will be set forth in part in the description which follows, and may be obvious from the description or learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 is a block diagram of a spread-spectrum communication transmitter and receiver;

FIG. 2 is a block diagram of a dual-mode transmitter according to the invention;

FIG. 3 is a block diagram of a dual-mode receiver according to the present invention;

FIGS. 4 and 5 are illustrations comparing exclusion zones around a microwave beampath;

FIG. 6 is a diagram of triangular cells arranged in a grid pattern;

FIG. 7 is a diagram of a triangular cell;

FIGS. 8 and 9 are diagrams showing an allocation of frequency bands;

FIG. 10 shows a dual-mode spread-spectrum modulator with two frequency bands;

FIG. 11 shows a programmable frequency generator;

FIG. 12 is a block diagram showing an alternative embodiment of a transmitter using a single frequency synthesizer for communicating over a plurality of frequency bands;

FIG. 13 is a block diagram showing another alternative embodiment of a transmitter using a single frequency synthesizer for allowing communication over a plurality of frequency bands;

FIG. 14 is a block diagram of a receiver using a single frequency synthesizer for demodulating signals that may be sent over more than one frequency band;

5 FIG. 15 is a diagram of frequency bands and sub-bands illustrating frequency pairs that may be generated by the transmitters shown in Figs. 11, 12 or 13;

FIGS. 16-1 to 16-6 are data rate and transmission charts for an embodiment of a DBCS system;

10 FIG. 17 is a diagram of an embodiment of a DBCS architecture;

FIGS. 18-1a and 18-1b document the formation of a sample 600 channel SSB-SC FDM baseband signal;

FIG. 18-2a and 18-2b are block diagrams of embodiments of a terminal transmitter and receiver;

15 FIGS. 18-4a, 18-4b, 18-5, 18-6, 18-8 and 18-9 are exclusion zone plots;

FIGS. 18-4c and 18-4d are OFS tower to mobile signal strength charts;

20 FIG. 18-7 is a sample link outage time/reliability chart;

FIG. 19-1 diagrams possible access service interfaces;

FIG. 19-2 diagrams an embodiment of a PCS architecture;

25 FIGS. 20-1 and 20-4 are propagation coefficient charts;

FIGS. 20-2 and 20-3 are frequency reuse factor charts;

FIG. 21-1 is an exclusion range chart;

30 FIGS. 21-3, 21-4, 21-5, and 21-6 are data rate charts; and

FIG. 21-7 is a self-interference diagram.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

35 Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings, wherein like

reference numerals indicate like elements throughout the several views. The disclosure of the invention may be supplemented by the contents of technical information appended to this specification in a technical appendix section. No admission is made as to possible prior art effect of any part of the technical appendix section.

Modern and proposed cellular telephone systems currently utilize high power, frequency, time, and/or code division multiplexed narrowband radio frequency communication techniques in conjunction with large cells to establish and maintain telephone communications. With the growing popularity of these systems, increased user capacity is required within a geographical area. One approach to providing increased capacity is microcells, which utilize comparatively much smaller cells as well as low power radio frequency techniques.

Traditional cellular systems have proven to be highly capital intensive in base station installations, on the order of several hundred thousand dollars per cell site, and therefore demand high operational and access fees. Proposed microcell systems would require a much lower capital investment per cell at a small fraction of cellular site installation cost, such that shop owners and other small operators could have a cell site easily instilled on their premises. Microcells potentially may be located in public access areas, airports, restaurants, shopping malls, banks, service stations, etc., as well as commercial or office facilities (utilizing wireless PBX, centrex, or key systems), and residential sites. A microcell user, thus, could utilize the same handset at home, in the office, or at most other public places where he or she typically would need access to telephone communications, in a cost effective way, and maintain a single telephone number. Public operational and access charges to the user could then be much lower, likely on the order of pay phone charges per call, not per minute.

A disadvantage of microcellular systems is their potential lack of incoming call accessibility. Potentially, one cannot place a call into the system to the remote user. Studies have been performed, however, that estimate that up to 5 80% of all calls made in traditional cellular systems are from the user outbound from the microcell user, and not inbound to the user. Even with no inbound access to the wireless microcell user, a potentially large market exists which has little need for incoming access, where users would be willing 10 to surrender incoming call access for the savings of a microcellular pager in the microcell handheld unit, which can provide for a level of incoming access to the user in the public environment.

15 Another disadvantage of microcells is practical handoff capabilities from cell to cell. Since the cells in a microcell system are small, the system becomes impractical to use from a moving vehicle since the user potentially could be passing through cells every few seconds, making handoffs 20 impractical. Microcellular systems may be designed such that there is no handoff capability between cells, which would provide for a wireless pay phone type of system. Since microcells are so small, system use in remote areas would be impractical due to the number of cell installations necessary 25 to provide complete coverage.

The present invention provides, in one embodiment, a dual-mode transmitter and receiver which achieves advantages of both systems, i.e. the range and mobility of traditional 30 cellular, and the low cost of microcellular. The dual-mode transmitter and receiver include a dual-mode cordless telephone which has as its first mode operational capabilities which allow cellular functionality, and a second mode which allows for microcellular operation. Functionality in the 35 first, or cellular, mode includes a relatively high power cellular telephone employing analog or digital voice techniques in conjunction with frequency, and/or time division

traditional narrowband radio techniques. Functionality in the second, or microcellular, mode includes a low power microcellular telephone using digital voice techniques in conjunction with frequency, time and/or code division spread spectrum radio techniques, where the cellular and microcellular functions either share the same frequency bands, or are offset from each other.

Figure 1 shows a block diagram of a spread-spectrum communication transmitter and receiver.

A spread-spectrum transmitter 1 comprises an input port 2 for input data 3, a chip sequence transmitter generator 4, and a transmitting antenna 5 for transmitting a spread-spectrum signal 6. A spread-spectrum receiver 7 comprises a receiver antenna 8, a chip sequence receiver generator 9, and an output port 10 for output data 11. A chip sequence 12 may be identically generated by both the transmitter generator 4 and the receiver generator 9, and appears essentially random to others not knowing the spreading code upon which it is based. The spread-spectrum signal 6 may have a spreading bandwidth which exceeds the bandwidth of the input data 3. The spread-spectrum signal 6 may also be modulated onto a communication channel having a center frequency, with the center frequency and the spreading bandwidth substantially defining a communication channel. The communication channel may also have a known signal dropoff for energy outside the limits of the channel. An extensive discussion of spread-spectrum communication, spreading codes, and chip sequences, may be found in R. Dixon, SPREAD-SPECTRUM SYSTEMS (2d ed. 1984).

In the exemplary arrangement shown in Fig. 2, a dual-mode transmitter in accordance with various aspects of the present invention is shown comprising an antenna 109, a mode controller 103, a mode select switch 104, transmitter-information processing means 101, a tunable-frequency

synthesizer 105, a chip-code generator 107, a spread-spectrum modulator 111, a narrowband modulator 113, a power amplifier 115, and an adjustable bandpass filter 117. The transmitter-information means may be embodied as an information device
5 101. The information device 101 may include source encoders such as Golay encoders, error correction coding, analog-to-digital converters, etc.

The spread-spectrum modulator 111 is coupled to the
10 information device 101 through mode select switch 104, the tunable-frequency synthesizer 105 and the chip-code generator 107. The narrowband modulator 113 is coupled to the information device 101 through mode select switch 104, and the tunable-frequency synthesizer 105. The power amplifier 115 is
15 coupled to the mode controller 103, the spread-spectrum modulator 111 and the narrowband modulator 113. The adjustable, tunable, bandpass filter 117 is coupled to the antenna 109, the power amplifier 115 and the mode controller 103.

20

Narrowband or spread-spectrum modulation is selected using the mode controller 103. The information device 101 processes the input information signal, while the tunable-frequency synthesizer 105 generates a carrier signal, and the
25 chip-code generator 107 generates a chip-code signal.

The mode controller 103 controls a mode select switch 104 which directs the processed information signal to the narrowband modulator 113 or the spread-spectrum modulator
30 111. The spread-spectrum modulator 111 modulates the carrier with the processed information signal and the chip-code signal as a spread-spectrum signal, when the mode select switch 104 has been selected for spread-spectrum modulation. The narrowband modulator 113 modulates the carrier with the
35 processed information signal as a narrowband modulated signal, when the mode select switch 104 is selected for narrowband modulation.

When the mode controller 103 is set to narrowband modulation, the power amplifier 115 amplifies the narrowband modulated signal. Where the dual modes function in distinct frequency bands, the power amplifier 115 may either be
5 wideband enough to function in both bands, or may be adjustable to function in the band pertaining to the mode in operation, with mode controller 103 controlling its operation accordingly. When the mode controller 103 is set to spread-spectrum modulation, the power amplifier 115 amplifies the
10 spread-spectrum signal. Similarly, with a narrowband modulation setting of the mode controller 103, the adjustable bandpass filter 117 has a bandwidth adjusted to a narrow bandwidth and corresponding frequency for passing the narrowband modulated signal. With a spread-spectrum setting
15 of the mode controller 103, the adjustable bandpass filter 117 has a bandwidth adjusted to a wide bandwidth and corresponding frequency for passing the spread-spectrum signal.

The present invention, as illustrated in Fig. 3,
20 also includes an embodiment as a dual-mode receiver. The dual-mode receiver may comprise a mode controller 103, a tunable-frequency synthesizer 105, a chip-code generator 107, an antenna 109, an adjustable bandpass filter 117, a preamplifier 205, a frequency converter 209, an IF amplifier
25 211, a mode select switch 104, a spread-spectrum despreaders 215, a spread-spectrum demodulator 217, a narrowband demodulator 213, and receiver-information processing means. The receiver-information means is embodied as a receiver-information processing device 219. The adjustable bandpass
30 filter 117, is coupled to the antenna 201 and to the mode controller 103. The preamplifier 205 is coupled to the adjustable bandpass filter 117 and to the mode controller 103. The frequency converter 209 is coupled to the preamplifier 205 and the tunable-frequency synthesizer 105. The IF amplifier
35 211 is coupled to the frequency converter 209. The spread-spectrum despreaders 215 is coupled to the chip-code generator 107 and through the mode select switch 104 to the IF amplifier

211. The spread-spectrum demodulator 217 is coupled to the spread-spectrum despreaders 215. The narrowband demodulator 213 is coupled through the mode controller 103 to the IF amplifier 211.

5

As with the dual-mode transmitter of Fig. 2, the mode controller 103 is used to select reception of narrowband or spread-spectrum modulation. The tunable-frequency synthesizer 105 generates a local oscillator signal, and the chip-code generator 107 generates a reference chip-code signal for comparison with the received chip code signal.

10

When the mode controller 103 is set to narrowband modulation, the adjustable bandpass filter 117 is adjusted to a narrow bandwidth and corresponding frequency for passing the narrowband modulated signal. With a spread-spectrum setting of the mode controller 103, the adjustable bandpass filter 117 is adjusted to a wide bandwidth and corresponding frequency for passing the spread-spectrum signal. The preamplifier 205 amplifies the filtered narrowband modulated signal when the mode controller 103 is set to the narrowband modulation setting, and amplifies the filtered spread-spectrum signal when the mode controller is set to the spread-spectrum modulation setting and is switch selectable to the appropriate band for each mode where the dual mode occupy non-contiguous or widely separated frequency bands. The frequency converter 209 converts using the local oscillator signal, the filtered narrowband modulated signal and the filtered spread-spectrum signal to an IF signal.

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Figures 2 and 3 illustrate the implementation of a dual-band, dual-mode transmitter and receiver, respectively, for use in any narrowband application with capability to switch to a separate frequency band while employing spread spectrum modulation/demodulation in the alternate operating band.

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Operation of the dual-band transmitter of Fig. 2 is as follows. Using transmitter-information processing device 101, input information may be filtered, analog-to-digital (A/D) converted if required, as determined by the mode switch control, and applied to either a narrowband or spread spectrum modulation process. Narrowband modulation is employed in a narrowband mode and spread spectrum modulation employed in a spread-spectrum mode. In either mode, the modulated carrier is applied to the dual-band RF power amplifier 115.

The tunable frequency synthesizer 105, which provides the proper carrier for either conventional narrowband or spread spectrum mode, is controlled by the mode switch controller 103, outputting only one of possibly many required transmit carrier frequencies for modulation at any one time.

After amplification, the proper modulated carrier signal, either conventional narrowband or spread spectrum, is applied to an adjustable, tunable bandpass filter 117 and then to the antenna 109. The pass band and frequency of the adjustable bandpass filter 117 is selected by the mode controller 103. This is necessary to meet transmission spurious signal level control standards.

A single, dual-band antenna 109 then acts as a transducer to convert the electrical RF signal from the power amplifier 115 and adjustable bandpass filter 117 to an electromagnetic signal for propagation to the receiver.

The mode controller 103 also controls the operation of a reference code generated by chip-code generator 107. The reference code is used as a spectrum-spreading function in the spread spectrum mode. The chip-code generator 107 would not operate in the conventional narrowband mode.

This transmitter configuration is applicable to any desired dual mode system in which one mode is used in a

conventional narrowband system, such as cellular telephones, while a second mode is employed for communicating with a spread spectrum system.

5 Receiver operation of the receiver in Fig. 3 is as follows. A received signal is converted by the antenna 109 from an electromagnetic signal to an electrical signal. The antenna 109 may or may not be common to the transmitter. The received signal is then applied to an adjustable bandpass
10 filter 117, which may or may not be common to the transmitter, and which is controlled by the mode controller 103. The adjustable bandpass filter 203 selects the proper conventional narrowband or spread spectrum operating signal and passes it through a preamplifier 205, whose output is applied to a
15 frequency converter 209.

The other input to the frequency converter 209 is a local oscillator signal generated by a tunable frequency synthesizer 105 whose frequency in turn is controlled by the
20 mode controller 103. The input signal is converted to an intermediate frequency (IF), which may be the same for either conventional narrowband or for spread spectrum signals. The receiver is assumed to be the superheterodyne type, and is illustrated as a single conversion receiver, but may also be
25 implemented by a dual or multi-conversion superheterodyne receiver without a change in the overall system's operation.

An output signal from the frequency synthesizer 105 is multiplied with the amplified input signal from the
30 preamplifier 205 selected by the input filter, in frequency converter 209 to produce the intermediate frequency signal. A tuned, fixed frequency IF amplifier 211 amplifies the received signal and applies it to a mode select switch 104 whose output is coupled to either the conventional narrowband signal
35 demodulator 213 or the spread-spectrum signal despreaders 215. The despreaders 215 use a reference code provided by the chip-code generator 107 to facilitate proper spread spectrum signal

selection and despreading. This reference code is controlled by the mode controller 103, and may be common to the transmitter shown in Fig. 2.

5 The spread-spectrum desreader 215 despreads, using the reference chip-code signal, the IF signal as a digitally modulated signal. The spread-spectrum demodulator 217 demodulates the digitally modulated signal as a digitally demodulated signal. The narrowband demodulator 213
10 demodulates the filtered narrowband modulated signal as a demodulated signal. The receiver-information device 219 processes the demodulated signal as an information signal.

15 Spread spectrum signals, after being despread, are demodulated by a spread-spectrum demodulator 217, separate from the narrowband demodulator 213. This is necessary because of the difference in conventional signal information modulation of the carrier is typically analog FM, while spread spectrum signals may employ digital modulation and may be
20 digital-to-analog (D/A) converted prior to processing. If the narrowband technique used employs digital modulation, a second narrowband D/A demodulator, similar to the spread spectrum demodulator, may be employed, or the spread spectrum demodulator may be eliminated and D/A demodulation, which may
25 be identical for both narrowband and spread spectrum modulation, may be included as a function of the received information processor.

30 After despreading, spread-spectrum demodulator 217 output signals are processed, using receiver-information device 219, by filtering, digital-to-analog conversion, and amplification, as necessary, to convert it to a form that is usable to the information output destination. Processing is selected by the mode switch control 103.

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 As in the transmitter of Fig. 2, more than two modes can be supported by the same general receiver configuration of

Fig. 3. This includes operation at multiple frequencies, use of multiple codes, multiple modulation formats, or time-sequential selection of operating mode.

5 The following illustrate application of aspects of the present invention, for particular modulation schemes.

One embodiment of the invention includes a telephone whose first mode comprises analog voice techniques and
10 traditional cellular frequency division multiplexed operation employing, but not limited to, narrowband radio frequency modulation techniques, such as FM, and whose second mode comprises microcellular operation including, but not limited to, digital voice commanding and/or compression techniques
15 coupled with spread spectrum radio frequency modulation, and/or time and/or frequency division multiplexing techniques, where the cellular and microcellular modes occupy common frequency bands. The microcellular mode also may include a paging function, which may utilize narrowband or spread
20 spectrum technologies, and occupy frequency bands common to the cellular and microcellular modes, or may be offset from both or either, and may be independent of the unit's telephone functionality.

25 Another embodiment of the invention includes a telephone whose first mode comprises cellular frequency division multiplexed operation employing, but not limited to, narrowband radio frequency modulation techniques, such as FM, coupled with digital voice commanding and/or compression
30 and/or time division multiplexing techniques, and whose second mode comprises microcellular operation including, but not limited to, digital voice compendium and/or compression techniques coupled with spread spectrum radio frequency modulation, and/or time and/or frequency division multiplexing
35 techniques, where the cellular and microcellular modes occupy common or distinct frequency bands. The microcellular mode may also include a paging function, which may utilize

narrowband or spread spectrum technologies, and may occupy frequency bands common to the cellular and microcellular modes, or may be offset from both or either, and may be independent of the unit's telephone functionality.

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It will be apparent to those skilled in the art that various modifications can be made to the described transmitter and receiver configurations without departing from the scope or spirit of the invention, and it is intended that the present invention cover modifications and variations of the techniques shown herein provided that they come within the scope of the appended claims and their equivalents.

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As previously noted with respect to Fig. 1, a spread-spectrum signal 6 may have a spreading bandwidth which exceeds the bandwidth of the input data 3. The spread-spectrum signal 6 may also be modulated onto a communication channel having a center frequency, with the center frequency and the spreading bandwidth substantially defining a communication channel, and the communication channel may have a known signal dropoff for energy outside the limits of the channel. It has been found by the inventors that a particular set of selected values for the spreading bandwidth and the center frequency provide a substantial and surprising advantage when using spread-spectrum techniques for wireless communication.

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In particular, it has been found by the inventors that a spreading bandwidth of about 10 megahertz (MHz) or less offers several advantages in spread-spectrum wireless communication. These advantages include:

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- o minimizing interference with microwave communication users when transmitting in a microwave communication band such as the 1850--1990 MHz communication band;

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- o minimizing interference with, and maximizing compatibility with, cellular communication users when transmitting in a cellular communication band such as the cellular communication bands near 800--
5 900 MHz and other cellular communication bands;
- o mitigating the effect of frequency-selective fading when transmitting using a spread-spectrum technique;
- 10 o allowing the same spread-spectrum technique to be used in other communication bands, such as the 902--928 MHz band and the 2400--2483.5 MHz band; and
- 15 o other and further advantages which are detailed in, and which would appear from, the technical appendix section to those of ordinary skill in the art, after perusal of the specification, drawings and claims.

Using a 10 MHz or smaller band for spread spectrum
20 communication when transmitting within a microwave communication band (such as the 1850--1990 MHz communication band) minimizes interference with microwave communication users in several ways. As a general matter, interference avoidance is a function of both geography and frequency
25 selection. Typically, microwave communication is directed over a beampath between a microwave transmitter and receiver. Because microwave stations provide critical services such as, for example, controlling the nation's electric power grid, the possibility of inadvertent disruption of such services
30 extremely serious. Accordingly, government regulations typically require that microwave stations such as licensed OFS receivers cannot be required to tolerate more than a set level (e.g., 1 dB) of interference in their areas of operation. Users of the microwave frequency bands within the geographic
35 area of licensed microwave stations therefore cannot operate in a zone which would cause more than 1 dB of interference to

the microwave station. This zone may be referred to as an exclusion zone.

Figures 4 and 5 show examples of exclusion zones for a specific traditional narrowband communication technique as compared to a specific type of spread spectrum communication technique. Figure 4 compares the size of exclusion zones 331 and 332 around a microwave beampath 330 under a theoretical freespace loss model. As can be seen in Fig. 4, the exclusion zone 332 for narrowband communication may be far larger than the exclusion zone 331 for spread spectrum communication. It can also be seen that the exclusion zones 331 and 332 extend farthest in the direction of the beampath 330. With respect to other directions, the exclusion zones 331 and 332 extend relatively farther out at 90 degrees to the beampath 330, but are relatively closer, for example, in the direction opposite the beampath 330 and at various other angles as depicted in Fig. 4.

In a similar manner, Fig. 5 compares the size of exclusion zones 341 and 342 around a microwave beampath 340 under a HATA loss model (median city suburban assumption). The exclusion zones 341 and 342 for Fig. 5, although derived from a different loss model, are similar in shape to those of Fig. 4.

Because of the particular shape of the exclusion zones 331, 332, 341 and 342 (as illustrated in Figs. 4 and 5), minimizing interference with microwave communication users may potentially be achieved by avoidance of the microwave beampath 330 or 340. It has thus far, however, been unappreciated that OFS avoidance is more difficult for signals, be they narrowband or spread spectrum signals, exceeding 10 MHz in bandwidth or extending over multiple OFS bands. The reason for such difficulty stems from the fact that approximately 94 percent of all OFS links are 10 MHz links. Thus, while it might be possible to select a 10 MHz band on which to transmit

so as to interfere with at most only a single 10 MHz OFS link, any signal wider than 10 MHz could potentially interfere with at least two and possibly more OFS links. This problem is exacerbated by the fact that, in and around many urban areas, OFS microwave beampaths of different frequency bands may not necessarily be parallel but may intersect in a variety of patterns. Thus, the existing geographic pattern of microwave links in most major cities would necessitate that, in many if not most cells (in the case of a cellular system), any signal wider than 10 MHz transmitted in microwave frequency bands would interfere with the beampath of more than one microwave station no matter how much frequency avoidance was employed.

In contrast, the present invention provides in one embodiment means for avoiding or minimizing interference with existing OFS links by selection of a particular frequency bandwidth for spread spectrum communication. In particular, this aspect of the present invention provides for a spread spectrum communication bandwidth that is 10 MHz or less in size. Given a known allocation of frequency bands for OFS users, the present invention in one embodiment allows for selection of a 10 MHz or smaller band for spread spectrum communication so as to avoid the beampath of existing fixed microwave users or, in the worst case, to potentially interfere with only a single microwave communication user. For example, if the selected band for spread spectrum communication is coextensive with or entirely within the bandwidth of a known 10 MHz OFS link, then, because OFS channels are frequency multiplexed, the spread spectrum communication signal can interfere with at most the one known 10 MHz link. Further, the spread spectrum transmitter 1 can be geographically located so as to minimize or avoid interference with that existing OFS link.

Another way in which aspects of the present invention minimize interference with microwave communication users is by using a spread spectrum signal for communication.

A spread-spectrum signal with its noise-like characteristics creates much less interference than a narrowband signal of comparable power. Approximately 83% of all OFS links use analog microwave systems which are highly susceptible to narrowband interference. The maximum allowable interference to a microwave receiver is commonly defined by the TSB10E standard as only a 1 dB rise in the receiver's noise threshold. A 10 MHz bandwidth spread spectrum signal may result in 1/100 (20 dB) less interference to an OFS receiver compared with a similar power 100 KHz bandwidth narrowband signal. The difference in interference is illustrated, for example, in Figs. 4 and 5. Figure 4 compares the exclusion zone 332 (assuming a 2 GHz microwave transmitter having a directional antenna at a height of 200 feet) of a 100 KHz narrowband signal with the exclusion zone 331 of a 10 MHz spread spectrum signal using a theoretical freespace loss model. The narrowband exclusion zone is 30 to 100 times larger than the spread spectrum exclusion zone. Figure 5 shows a similar comparison using a HATA loss model (median city suburban assumption).

A further advantage of using a 10 MHz or smaller spread spectrum communication bandwidths is that it provides an easy migration path into the existing bands of OFS users if the OFS users can be relocated to another band.

Information relating to construction of a spread-spectrum communication system using a 10 MHz or less spreading bandwidth and having known center frequencies may be found in detail in the technical appendix section. The specification, drawings, claims, and the technical appendix, in combination, contain a written description of the invention, and the manner and process of making and using it, in such full, clear, concise and exact terms as to enable any person skilled in the art to make and use the same.

For example, a spread spectrum system for communicating over a 10 MHz or smaller frequency band may be part of a cellular network. The system may comprise a plurality of base stations 381 arranged in an approximately triangular grid 383 covering a service area, as shown in Fig. 6. Regions surrounded by three base stations 381 may comprise triangular cells 380. Each base station 381 may consist of six transmitters, each separately driving a 60° sector antenna. For aesthetic reasons, conformal mount, flat antennas mounted on the sides of buildings may be used in some areas where obtaining zoning for tower mounted antennas is difficult or economically undesirable. Although not required, the frequency of each transmit sector can be different if necessary to minimize interference with existing OFS and PCS services. The data transmission rate may be independently set from cell to cell; that is, different sectors of a base station may transmit at different rates.

A triangular service cell 380 is shown in Figure 7. Three base stations 381 having transmitters form the corners of the triangular service cell 380. The base stations 381 send high speed data using appropriate 60° antennas and may also use different spreading codes and/or different frequencies. Because different frequencies may be used, the described system allows for OFS frequency avoidance on a cell sector by cell sector basis. Within the data stream, block interleaving and convolutional encoding may also be used to further mitigate fading and interference effects. An additional low rate base state/sector identifier data stream, unique to each transmitter, is employed to facilitate mobile unit location determination and data transmission query processing.

In one configuration, the data on the outbound transmission in each triangular cell 380 may be different. Because each transmitter can also use a different spreading code, at a receiver 382 the signals can be separated and

processed independently prior to data system combining. As shown in Fig. 7, the receiver 382 within a triangular cell 380 may be in a position to receive signals from at least three base stations 381. The receiver 382 independently despreads the three signals, performs soft decision data demodulation, and combines the data streams prior to convolutional decoding. Code based, variable delays may be introduced to synchronize data streams prior to combining.

The base stations 381 may be synchronized using a global positioning system. By including base station position in the data stream, a user can determine his or her location to an accuracy of about 30 feet by measuring pseudorange to each of the three transmitters located at the base stations 381. The user can also obtain timing information within an accuracy of about 30 to 100 nanoseconds.

The above described system employing triple transmission and spread spectrum communication has several important advantages. The system significantly reduces sensitivity to signal shadowing effects caused by buildings, hills, and similar obstacles. The system mitigates multipath fading effects and enhances error correction coding performance. Further, if interference is encountered at one frequency, a signal may be transmitted at a different frequency by one of the other two base stations 381 of the triangular cell 380. Also, the system architecture reduces required transmit power and, consequently, reduces the potential for OFS interference. Low power transmitters (e.g., as low as 100 mW) may be used in regions where OFS interference exists.

When base stations 381 are located close together, the maximum data transmission rate is determined primarily by mutual interference considerations, while at wider separations of base stations 381, the data transmission rate is limited by noise. Even in areas near an OFS user on the same frequency,

a triangular grid of transmitters 1 to 2 km apart may provide 600 kbit/s raw data rate at a bit rate error of 10^{-6} . A compact receiver may be capable of combining multiple simultaneous 1.5 Mbit/s transmissions in a single contiguous 10 MHz band of shared spectrum. The receiver may have the option of selecting any of the available transmission frequencies based on local propagation characteristics and received $S/(1+N)$. A user experiencing good quality reception may request a higher data rate if total traffic warrants.

The system for transmitting spread spectrum signals over a 10 MHz bandwidth may employ time division multiplexing or duplexing in order to separate users. Time separation avoids interference problems, as the interference in any single time slot is simply that created by a single user. Thus, multiple users could share the same 10 MHz bandwidth while creating the interference of only a single continuous user. In contrast, in other systems the aggregate interference per cell typically rises proportionally with the number of users leading to interference problems with OFS and other users sharing the electromagnetic spectrum. Time division multiplexing or duplexing may be combined with frequency division multiplexing or duplexing in order to increase the number of separate users.

Another aspect of the invention relates to a technique for spread-spectrum communication which uses more than one frequency band, particularly frequency bands including the 902--928 MHz, 1850--1990 MHz, and 2.4--2.4835 GHz frequency bands. As noted above, the spread-spectrum signal 6 may be modulated onto a communication channel. The communication channel may be selected from frequencies in one of a plurality of frequency bands, including the 902--928 MHz, 1850--1990 MHz, and 2.4--2.4835 GHz frequency bands, and including the 1910--1930 MHz frequency band or other future unlicensed frequency bands, or other designated frequency bands.

In this aspect of the invention, a spreading bandwidth of 10 MHz may be used, or a different spreading bandwidth which may be more or less than 10 MHz. A different spreading bandwidth may be used from time to time; a different spreading bandwidth may be used for communication in different frequency bands, or for different uses.

In a preferred embodiment, the invention provides for changing the frequency band onto which the spread-spectrum signal 6 is encoded upon a change in environment or other control trigger. For example, the 902--928 MHz and 2.4--2.4835 GHz bands may be used for private access spread-spectrum communication, such as with a PBX, PABX, residential telephone, key system, Centrex system, or other related system, while the 1850--1990 MHz band may be used for public access spread-spectrum communication, such as public telephone access. In a preferred embodiment, a spread-spectrum transmitter 1 may be embodied in a handset 13 and may dynamically switch from one frequency band to another based on whether it is able to access a local PBX or PABX 14 via spread-spectrum communication. In particular, the handset 13 may be capable of switching between the 1850--2200 MHz band and the 2400--2485 MHz band, or between two sub-bands within those bands. In place of the PBX or PABX 14, a related system such as a residential telephone, key system, or Centrex system may be readily substituted. Alternatively, the transmitter 1 may dynamically switch from one frequency band to another based on local propagation characteristics and received $S/(1+N)$.

Figure 8 shows one possible scheme for dividing the 1850--1990 MHz and 2400--2485 MHz bands into sub-bands of 10 MHz or 5MHz each. A first bandwidth 400 comprising frequencies from 1850--1930 MHz may be divided into sub-bands 402 of 10 MHz or 5 MHz each. Thus, if the first bandwidth 400 is divided into sub-bands 402 of 10 MHz, then eight channels could be provided, while if divided into sub-bands 402 of 5

MHz, then sixteen channels could be provided. Likewise, a second bandwidth 405 comprising frequencies from 2400--2480 MHz may be divided into sub-bands 406 of 10 MHz or 5 MHz each. A dual mode phone 410 provides access to a select one of the plurality of sub-bands 402 in the first bandwidth 400, and may be switched to provide access to a select one of the plurality of sub-bands 406 in the second bandwidth 405.

While transmitting in a sub-band 402 within the first bandwidth 400, which comprises licensed frequency band to which OFS users would have access, the dual mode phone 410 may transmit using spread spectrum communication taking advantage of CDMA and/or TDMA methods in order to minimize interference with OFS microwave users. If no OFS user is present, the dual mode phone 410 may of course transmit using conventional narrowband techniques. While transmitting in a sub-band 406 within the second bandwidth 405, which comprises unlicensed frequencies available to PCS systems such as PBX, Centrex or other systems, the dual mode phone 410 may transmit using spread spectrum communication taking advantage of CDMA and/or TDMA methods in order to minimize interference with existing users, if any, or may transmit using conventional narrowband techniques. Thus, the same dual mode phone 410 may access a cellular system, for example, in a first bandwidth 400 but, by operation of a switch, may access a private access network such as a PBX or Centrex in a second bandwidth 405.

Figure 9 shows a similar scheme for communicating in either one of two different frequency bands.

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Information relating to construction of a spread-spectrum communication system which uses more than one frequency band, particularly frequency bands including the 902--928 MHz, 1850--1990 MHz, and 2.4--2.4835 GHz frequency bands may be found in detail in the technical appendix section, as well as in the description set forth earlier herein. The specification, drawings, claims, and the

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technical appendix, in combination, contain a written description of the invention, and the manner and process of making and using it, in such full, clear, concise and exact terms as to enable any person skilled in the art to make and
5 use the same.

For example, Fig. 10 shows a dual-mode spread-spectrum modulator with two frequency bands. The dual-band spread-spectrum modulator uses a single, relatively narrow,
10 synthesizer to serve two operating frequency bands. In the lower frequency band, the synthesizer may operate in a high-side injection mode, while in the higher frequency range, the synthesizer may operate in a low-side injection mode. In a preferred embodiment, the lower frequency range may comprise
15 about 1850 to 1990 megahertz, while the higher frequency range may comprise about 2400 to 2483.5 megahertz.

The operation of the device shown in Fig. 10 will now be explained in more detail. A first frequency source 401
20 may generate a first frequency f_1 402, while a second frequency source 403 may generate a second frequency f_2 404. The first frequency f_1 402 and the second frequency f_2 404 may be coupled to a multiplier 405, which may generate a bimodal signal 406 with a frequency distribution over two frequency
25 ranges f_L 407 and f_H 408. In a preferred embodiment, the lower of the two frequencies f_L 407 ($f_L = f_1 - f_2$) may range from about 1850 to 1990 megahertz, while the higher of the two frequencies f_H 408 ($f_H = f_1 + f_2$) may range from about 2400 to 2483.5 megahertz. When one of the two frequencies f_1 and f_2 ,
30 e.g., f_2 is chosen between the two ranges, e.g., about 2200 megahertz, the other frequency, e.g., f_1 may be chosen between about 300 and 440 megahertz.

The bimodal signal 406 may be coupled to a binary
35 encoder 409, for encoding a data stream 410. The data stream 410, comprising a sequence of data bits 411, may be coupled to the binary encoder 409, which may generate a first frequency,

e.g., fL 407, when a data bit 411 in the data stream 410 is a "0" bit, and may generate a second frequency, e.g., fH 408, when a data bit 411 in the data stream 410 is a "1" bit.

5 The present invention also provides for monitoring a frequency in each band (or transmitting to a frequency in each band) at once, because both $(f_1 + f_2)$ and $(f_1 - f_2)$ can be stepped down to the same intermediate frequency with a single local oscillator. When the intermediate frequency is 260 MHz
10 and the local oscillator is set to 2180 MHz, the present invention allows operation at both 1920 MHz and 2440 MHz. When the local oscillator is set 10 MHz greater, the present invention then allows operation at both 1930 MHz and 2450 MHz, i.e., two frequencies each 10 MHz greater. Thus, for paired
15 frequencies, the present invention allows reception or transmission on either frequency (or both) in the pair.

Figure 11 shows a programmable frequency generator.

20 A reference frequency signal 501 may be coupled to a multiplier 502. The multiplier 502 may generate a signal $f(s)$ 503, which may be coupled to a voltage-controlled oscillator (VCO) 504. The VCO 504 may be coupled to an output node 505, which provides an output frequency signal 506, and may also be
25 coupled in a feedback configuration to the multiplier 502 by way of a programmable divide-by-N counter 507. The programmable divide-by-N counter 508 may be programmed by a set of control lines 509. In one embodiment, the divide-by-N range of the programmable divide-by-N counter 507 comprises 23
30 steps, from 205 to 234.

Figure 12 is an alternative embodiment of a transmitter using a single frequency synthesizer for communicating over a plurality of frequency bands. In Fig.
35 12, an incoming data stream 601 to be modulated is provided to a spread spectrum encoder 602, which encodes the data stream 601 and outputs a spread spectrum signal 605. The spread

spectrum encoder 602 may encode the data stream 601 by modulating it with a PN code, or by employing an M-ary spread spectrum technique. The spread spectrum signal 605 is connected to a modulator 609. A carrier signal having a frequency f_1 is generated from a signal source 603 and is also connected to modulator 609. Modulator 609 outputs a modulated spread spectrum signal 607.

The modulated spread spectrum signal 607 is connected to another modulator 610. A frequency synthesizer 606 (e.g., such as shown in Fig. 11) generates a programmable frequency signal 608, which is also connected to the modulator 610. The programmable frequency signal 608 has a center frequency of f_n , which may be programmed by control lines 509 such as shown, for example, in Fig. 11. Modulator 610 outputs a bimodal signal 611 having frequency components at frequencies $f_1 + f_n$ and $f_1 - f_n$.

The bimodal signal 611 is connected to a wideband amplifier 615. The wideband amplifier 615 is controlled by a band select signal 616, which causes the wideband amplifier 615 to perform at an operating point tailored for either the frequency $f_1 + f_n$ or the frequency $f_1 - f_n$. An output of the wideband amplifier 615 is connected to two bandpass filters 619 and 620. One bandpass filter 619 has a center filtering frequency of $f_1 + f_n$, and the other bandpass filter 620 has a center filtering frequency of $f_1 - f_n$. The first bandpass filter 619 passes the portion of the amplified signal having frequency components at $f_1 + f_n$ while attenuating the frequency components at $f_1 - f_n$, and the second bandpass filter 620 passes the portion of the amplified signal having frequency components at frequency $f_1 - f_n$ while attenuating the frequency components at frequency $f_1 + f_n$. Bandpass filter 619 outputs an output signal 622 having a frequency $f_1 + f_n$, while bandpass filter 620 outputs an output signal 623 having a frequency $f_1 - f_n$.

Thus, the Fig. 12 transmitter allows generation and transmission, using a single frequency synthesizer 606, of a signal in either or both of two frequency bands, wherein the frequency $f_1 + f_n$ lies in one frequency band and the frequency $f_1 - f_n$ lies in the other frequency band. Figure 15 is a diagram of frequency bands and sub-bands illustrating frequency pairs that may be generated for a selected f_1 and f_n . In Fig. 15, a pair of frequency bands F_H and F_L are each divided into a plurality of sub-bands 750. The higher frequency band F_H is divided into sub-bands SBH1, SBH2, ..., SBHN, while the lower frequency band F_L is divided into sub-bands SBL1, SBL2, ..., SBLN. The sub-bands SBH1...SBHN and SBL1...SBLN are paired, with the highest of the sub-bands SBH1 in the high frequency band F_H paired with the lowest of the sub-bands SBL1 in the low frequency band F_L , the second highest of the sub-bands SBH2 in the high frequency band F_H paired with the second lowest of the sub-bands SBL2 in the low frequency band F_L , and so on, until the lowest of the sub-bands SBHN in the high frequency band F_H is paired with the highest of the sub-bands SBLN in the low frequency band F_L , thereby resulting in frequency pairs PAIR-1, PAIR-2, ..., PAIR-N. The high frequency band F_H may comprise all or a portion of the band ranging from 1850 MHZ to 1990 MHZ, while the low frequency band F_L may comprise all or a portion of the band ranging from 2.4 MHZ to 2.485 MHZ. The sub-bands SBH1...SBHN and SBL1...SBLN need not be contiguous within each of the main frequency bands F_L and F_H .

In operation, the programmable frequency synthesizer 606 is programmed to select a frequency f_n , preferably selected from one of a discrete group of N frequencies corresponding to the frequency pairs PAIR-1, PAIR-2, ..., PAIR-N. The largest selected f_n allows operation over the frequency sub-band pair denoted PAIR-1, while the smallest selected f_n allows operation over the frequency sub-band pair denoted PAIR-N, with the frequency selections for f_n between the smallest and largest values of f_n corresponding to frequency

pairs PAIR-2 through PAIR-(N-1). Thus, by changing the frequency f_n in discrete steps, the transmitter of Fig. 12 can be operated over a different pair of frequency sub-bands 750.

5 While the Fig. 12 embodiment is described with the frequency f_1 greater than frequency f_n , it is also possible to have frequency f_n be greater than frequency f_1 . In such a case, the relative frequency difference between the higher frequency signal at a frequency $f_n + f_1$ and the lower
10 frequency signal at a frequency $f_n - f_1$ will be a constant $2 \cdot f_1$ as the frequency f_n is varied according to control lines 509 or other programming means.

 Figure 13 is another embodiment of a transmitter
15 using a single frequency synthesizer for allowing communication over a plurality of frequency bands. In Fig. 13, a data stream 651 is encoded by a spread spectrum encoder 652 in a similar manner to Fig. 12. A spread spectrum signal 655 output from the spread spectrum encoder 652 is modulated
20 with a carrier signal 654 from a signal source 653 by modulator 659. The carrier signal 654 has a frequency f_1 . The modulator output 657 is connected to another modulator 660. A frequency synthesizer 656 (e.g., such as the one shown in Fig. 11) generates a programmable frequency signal 658,
25 which is also connected to the modulator 660. The programmable frequency signal 658 has a center frequency of f_n , which may be programmed by control lines 509 such as, for example, shown in Fig. 11. Modulator 660 outputs a bimodal signal 611 having frequency components at frequencies $f_1 + f_n$
30 and $f_1 - f_n$.

 The bimodal signal 661 is connected to two narrowband power amplifiers 670 and 671. One narrowband power amplifier 670 is configured to operate at a frequency of $f_1 +$
35 f_n , while the other narrowband power amplifier 671 is configured to operate at a frequency $f_1 - f_n$. Outputs from each of the narrowband power amplifiers 670 and 671 are

provided to an analog multiplexer 675 (or a set of switches), which selects one of the two outputs from amplifiers 670 and 671 in response to a band select signal 676. The multiplexer 675 may be configured so that it selects one or both of the
5 amplifier outputs, thereby allowing operation over a single frequency band or two frequency bands, and in either case using a single frequency synthesizer 656. The Fig. 13 transmitter operates over paired frequency sub-bands SBH1...SBHN and SBL1...SBLN (see Fig. 15) in a manner similar
10 to the Fig. 12 transmitter, depending on the frequency f_n selected for the programmable frequency signal 658.

Figure 14 is a block diagram of a receiver for receiving and demodulating signals that may be sent over two
15 frequency bands. In the Fig. 14 receiver, a transmitted signal 703 is received by an antenna 700 and provided to a switch 709. In one position A, the switch 709 connects to a first bandpass filter 714 having a center filtering frequency of $f_{IF} + f_n$, while in another position B, the switch 709
20 connects to a second bandpass filter 715 having a center filtering frequency of $f_{IF} - f_n$. In a preferred embodiment, frequency f_{IF} is selected as frequency f_1 used in the transmitter.

25 Outputs from each of the bandpass filters 714 and 715 are connected to another switch 710. In a first position A, the switch 710 connects to the first bandpass filter 714, while in another position B, the switch 710 connects to the second bandpass filter 715.

30 Switches 709 and 710 are controlled by a band select signal 719. When the switches 709 and 710 are set in position A, the Fig. 14 receiver is configured to detect signals sent over a frequency band centered at $f_{IF} + f_n$, and when the
35 switches 709 and 710 are set in position B, the receiver is configured to detect signals sent over a frequency band centered at $f_{IF} - f_n$. While two switches 709 and 710 are shown

in Fig. 14, the same result may be achieved by using only a single switch 709 or 710. A variety of other selection means could also be utilized.

5 The output from switch 710 is connected to a multiplier 720. A frequency synthesizer 721 generates a programmable frequency signal 722 having a frequency f_n . The programmable frequency signal 722 is also connected to the multiplier 720. The frequency f_n is selected to match the
10 desired frequency sub-band pair PAIR-1, PAIR-2, ... or PAIR-N, and therefore can monitor either of the two sub-bands 750 comprising the pair, depending on the setting of the band select signal. By switching the frequency f_n of the programmable frequency signal 722, the Fig. 14 receiver can be
15 adjusted to monitor two other frequency sub-bands 750. The sub-bands 750 that can be monitored by changing frequency f_n have the same pattern as shown in Fig. 15 -- that is, the highest sub-band SBH1 in the high frequency band F_H is paired with the lowest sub-band SBL1 in the low frequency band F_L , and
20 the lowest sub-band SBHN in the high frequency band F_H is paired with the highest sub-band SBLN of the low frequency band F_L .

 By replacing switches 709 and 710 with a connection
25 to both the A and B positions, the Fig. 14 receiver can be modified to simultaneously monitor two frequency bands, i.e., the frequency bands centered at frequencies $f_{IF} + f_n$ and $f_{IF} - f_n$.

30 Multiplier 720 outputs a downconverted signal 725. The downconverted signal 725 is provided to an IF/demodulation block 730, which demodulates the downconverted signal 725 to recover the original information modulated thereon. The demodulation block 730 operates at the frequency f_{IF} (i.e.,
35 f_1), and may comprise a frequency source for generating a frequency f_1 , and/or a spread spectrum decoder and demodulator.

As with the dual-band transmitters previously described, the frequency f_n in the dual-band receiver of Fig. 14 may be selected as larger than the frequency f_1 , in which case the bandpass filter 714 may be configured to have a center filtering frequency of $f_n + f_{IF}$, and bandpass filter 715 may be configured to have a center filtering frequency of $f_n - f_{IF}$. Thus, the frequency sub-bands to be monitored would be separated by a fixed $2 \cdot f_{IF}$ as the frequency f_n is varied among its programmable frequency values.

Alternative Embodiments

While preferred embodiments are disclosed herein, many variations are possible which remain within the concept and scope of the invention, and these variations would become clear to one of ordinary skill in the art after perusal of the specification, drawings and claims herein.

For example, information which is encoded for transmission is occasionally referred to herein as "data", but it would be clear to those of ordinary skill in the art, after perusal of this application, that these data could comprise data, voice (encoded digitally or otherwise) error-correcting codes, control information, or other signals, and that this would be within the scope and spirit of the invention.

Technical Appendix - Excerpts of FCC Submissions

The immediately following sections contain excerpts of technical reference submissions and specifications which were submitted to the Federal Communications Commission in the United States. These sections were included as the "TECHNICAL APPENDIX" in U.S. Application Ser. No. 08/293,671 from which priority is claimed, and have been edited to reduce redundancies.

37
SUMMARY

The stage has been set for another breathtaking leap forward in the U.S. Information Age. Increased availability of inexpensive computing power and mass storage has created enormous theoretical capabilities to create, manipulate, and process data. These computer-based advances could vastly expand opportunities for increased efficiency, productivity, and innovation for our country.

But these potential benefits from personal computing to American business and consumers are contingent on the ability to interchange timely, usable data with other information providers and users. While transmission technologies have evolved that efficiently permit point-to-point communications between users, no systems have been effectively deployed to respond to users' needs for point-to-multipoint mass information distribution. Thus while much lip service is paid to "electronic publishing," almost all information is still distributed on paper or by mail, including the rulings of this Commission and even computer software itself.

In this request, Omnipoint Corporation, Oracle Data Publishing, Inc., and McCaw Cellular COmmunications, Inc. (collectively, "Petitioners") propose an innovative system that would provide a high speed, high volume information "superhighway" to address the public's needs -- the Data BroadCast Service ("DBCS"). This service would enable many important applications to be delivered at a small fraction of the cost of fiber, satellite, or landline distribution, sustainable by private funding sources, and with operations commencing within 24 months. In addition, because DBCS is a broadcast rather than a landline system, it offers many advantages for portable applications that a national fiber optic, satellite, or wireline systems cannot.

Although falling under the broad umbrella of services to be considered by the Commission as "personal communications services," the DBCS proposal is fundamentally distinct from any service contemplated to date:

- *DBCS efficiently utilizes spread spectrum sharing techniques to coexist with incumbents 1850-1990 MHz licensees.* DBCS capitalizes on the use of advanced spread spectrum technology in a one-way format that permits DBCS to co-exist with current microwave operations.
- *DBCS broadcasts data.* Unlike data transmission services relying upon virtual circuits, i.e., establishing a two-way path between two points, DBCS utilizes an efficient and highly reliable one-way broadcast to bring data transmission within the realm of consumer communications.
- *DBCS transmits data at unparalleled speed.* The DBCS network contemplates transmission speeds of up to 1.5 Mbit/s, which would allow the network to transmit an average sized book in less than 5 seconds to millions of users simultaneously, thus dramatically lowering incremental costs for distributing information and making a huge variety of services available from a single device.
- *DBCS has modest spectrum requirements.* DBCS can achieve these significant data transmission rates into low cost devices using only 10 MHz of shared spectrum. This 10 MHz can be shared with existing microwave licensees and possibly with other competing spread spectrum DBCS providers. Any additional spectrum that might be granted would allow further increases in speed and throughput.
- *DBCS can provide ubiquitous service.* The benefits of DBCS are not limited to major metropolitan areas. DBCS can provide highly economic, ubiquitous coverage to even the most remote and rural areas of the continental U.S.

These functional characteristics of DBCS not only embody a number of highly advanced technologies, but also an entirely new way of thinking about data transmission.

What DBCS means for information users and providers is a dramatic change in the availability of timely data in electronic form:

- The entire daily public output of governmental information — rulings, press releases, studies, records, requests from local, state, federal and military sources — can be distributed at a small fraction of current costs, without paper.

Moreover, it will be automatically filed and stored at each end user site for later retrieval or printing.

- Because DBCS utilizes powerful encryption and access authorization standards, it can also be used by the government efficiently to distribute non-public information internally. Similarly, it also could be used by business to distribute information among employees, selected customers, or to the general public.
- The extreme high speed and low unit cost of DBCS allow it to solve the growing problem of maintaining complex, illustrated, or multimedia documentation at many sites nationwide. This documentation — for airlines, military equipment, large vehicles, manufacturing devices, farm implements, construction tools, computers, and computer software systems — is now delivered for the most part on paper, or on mailed electronic media, and is a major expense for American industry. Although electronic publishing systems have allowed business to improve the efficiency of document preparation, DBCS is needed to allow efficient distribution.
- Schools could receive broadcasts of textbooks, including color graphics, updates, and curriculum materials on a highly cost effective basis. With the cooperation of the publishing industry, vast collections of information can be delivered to local libraries that could not possibly afford or support similar collections on paper or if delivered by mail. Moreover, the information can be updated automatically and accessed locally without the need for the expensive high-speed two-way lines that would be required if the data were centrally stored and accessed remotely.
- Universities and research institutes, regardless of size, could automatically receive broadcasts of updated search index information for journals and specialized research information, allowing the users to execute database retrieval searches on their computers. Since the searching functions are done "off-line," and downloading of actual articles is performed separately, database retrieval costs would be much lower. This model of distributed indices and off-line searching would dramatically lower the cost and efficiency of the nation's existing on-line data services industry, thereby making more information available at lower prices to more people.
- New publishing enterprises and self-publishing would be greatly assisted by this new service. DBCS would allow authors to create electronic books that could be distributed throughout the nation at costs which are orders of magnitude lower than paper. An illustrated book-length manuscript could be sent to millions of recipients throughout the nation for a distribution cost of a few dollars. Not a few dollars each; a few dollars for the entire nation.

- Computer users could receive broadcasts of upgrades to software packages that would be automatically installed on the user's computer, greatly lowering the cost to both users and vendors, while also increasing ease of use. Similarly, the documentation for the software could also be delivered by DBCS. America now runs on software, and the best selling computer software titles now outsell any new books, periodicals, movies or music.
- All existing news and financial services can be carried by DBCS and accessed individually by authorized subscribers. A financial analyst could receive minute by minute broadcast news that was filtered to allow the user to track all stories concerning a specific company, a market group, or, for example, the progress of U.S./Mexican trade negotiations. Subscribing to a new service can be accomplished with a single telephone call, and new subscribers can be activated without installing leased lines or VSAT systems. By accommodating all services and subscribers in a single network, DBCS will greatly expand the potential for current and new electronic publishing, as a central market stimulates commerce.
- Medical institutions could receive broadcast information updates regarding new treatment methods, newly available therapies, and disease control statistics, including detailed illustrations and raw data results that are not now possible to distribute electronically at reasonable cost.
- Because of the inherent efficiency of a broadcast topology, DBCS would also allow the creation of a national electronic mail delivery system that would offer message rates dramatically lower than current e-mail (or land mail) systems, while allowing the delivery of images, graphics and facsimile that current landline dependent services cannot cost-effectively support.

Since all of this information is provided in a manipulable, electronic form, users can optimize their use of the data in highly personal ways to enhance their productivity and facilitate their information processing tasks.

In order to provide these significant public benefits, DBCS relies upon advanced technology direct sequence spread spectrum devices and associated network technology. These technological advances were developed by Omnipoint, one of the DBCS principals. Since 1987, Omnipoint has been conducting laboratory research and computer modeling, and

it began limited field trials in 1990 under its own experimental licenses to validate a DBCS network that would allow:

- *High Performance Receivers.* Petitioners' advanced technology will permit each DBCS user to receive up to 1.5 Mbit/s data transmissions from multiple simultaneous sources in a small, low power, safe, inexpensive, and relatively long battery life mobile unit. DBCS receivers support a data rate that is orders of magnitude faster than existing FM technologies and a transmission range orders of magnitude greater than comparably fast technologies.
- *Shared Use of Existing Spectrum.* DBCS has been designed to coexist with the Operational Fixed Service ("OFS") users in the 1850-1990 MHz band. Through a number of innovative techniques made possible through the use of advanced spread spectrum technology and taking advantage of the one-way characteristic of the broadcast service, DBCS can be deployed without displacing existing users of the band.

These innovations are significant advances over the state of the radio art allowing Petitioners to realize a cost effective, high speed, high volume, wireless data superhighway today, and without consuming massive spectrum resources or requiring the construction of universal fiber service.

Petitioners have designed DBCS as a comprehensive answer to information providers' data transmission and management needs. Technically, DBCS responds to widespread public demand for inexpensive, high speed, high volume nationwide digital data delivery. DBCS is an enabling technology that will permit nearly ubiquitous access to up-to-the-minute information and allow economic delivery of a rich variety of new information-based services designed to promote productivity and efficiency. The service will add a new dimension to personal computing and personal communications.

Omnipoint Corporation ("Omnipoint"), Oracle Data Publishing, Inc. ("Oracle"), and McCaw Cellular Communications, Inc. ("McCaw") (collectively, "Petitioners") jointly request a pioneer's preference for an innovative Data Broadcast Service ("DBCS"). As detailed below, DBCS will offer the public inexpensive access to a reliable and secure nationwide information superhighway operating at speeds up to 1.5 megabits per second ("Mbit/s"). This technological breakthrough relies on a small, low cost receiver capable of combining multiple simultaneous 1.5 Mbit/s transmissions in a single contiguous 10 MHz band of shared spectrum. Significantly, Petitioners' proposed use of 1850-1990 MHz can be integrated into the band by sharing with existing terrestrial licensees — permitting an extraordinary new use of spectrum without displacing established users.

Petitioners represent the combined spread spectrum, data processing, and wireless communications strengths of Omnipoint, Oracle, and McCaw. Drawing from the collective resources of these industry leaders, Petitioners designed DBCS as a complete Information Age solution to information providers' needs for wide area, high speed, or high volume data delivery. The proposed service will allow inexpensive, ubiquitous access to a multitude of information sources and enable economic delivery of many needed new information-based services, including several contemplated for the proposed national fiber optic data network. Petitioners' efforts to pioneer this innovative new service warrant grant of a preference in the licensing of DBCS providers.¹

I. PETITIONERS' QUALIFICATIONS AND EXPERIENCE

Petitioners are a high technology venture formed to advance a comprehensive solution for providing accessible, functional, timely data on a highly cost-effective basis. The venture represents the collective strengths and resources of three industry leaders. It combines Omnipoint's knowledge of spread spectrum and network design, Oracle's experience in data management, and McCaw's understanding of wireless communications. Accordingly, Petitioners hold unique qualifications to fulfill DBCS's potential for improving productivity, increasing access to information, and increasing the utility of information.

¹ Petitioners believe that DBCS falls within the realm of services currently being considered as PCSs and that the general licensing and service rules adopted for PCSs can be appropriately modified to reflect DBCS concerns. Accordingly, Petitioners are requesting a waiver of the pioneer's preference requirement to file an associated petition for rulemaking. See *Pioneer's Preference Reconsideration Order*, FCC 92-57 at ¶ 18 (rel. February 26, 1992). In the event that Petitioners' waiver request is denied, Petitioners will file a petition for rulemaking within the prescribed 30 day period.

Omnipoint is the country's leading manufacturer of true direct sequence handheld spread spectrum technology. With almost 300 man-years of experience in the design and development of spread spectrum systems, Omnipoint was the first company to develop handheld spread spectrum phones, to develop a palm sized spread spectrum modem, to test spread spectrum in microcells, to test spread spectrum phones with AIN features, to operate in conjunction with cable TV networks, to operate spread spectrum phones in the unlicensed bands, and, in late 1991, to demonstrate spread spectrum phones in the 1850-1990 MHz band. Omnipoint's advanced technology gallium arsenide integrated receiver, which allows Omnipoint's techniques to be used anywhere from 800 MHz to 2.5 GHz, is the basis of the only wireless spread spectrum network system capable of handling voice, data, and video in portable products.

Oracle is the nation's largest provider of database software and services, and America's third largest software firm overall, with projected revenues of over one billion dollars in its current year. Oracle's relational database management system ("RDBMS") is the standard for relational database products worldwide, commanding a majority of the RDBMS market. Oracle's RDBMS currently functions on over 80 computer platform including personal computers, workstations, minicomputers, and mainframes. The company's expertise in developing and managing database software that performs across a wide number of platforms brings to the venture the experience necessary to manage the extensive information that will be transmitted over the DBCS network for system managers, information providers, and information users. Oracle also has a large national network of

sales offices and support personnel, including many technical assistance representatives, that could form an integral part of a customer support network.

McCaw is the nation's leading provider of wireless personal communications services. McCaw and its affiliate, LIN Broadcasting Corporation, have ownership positions in over 100 cellular markets across the country with nearly 100 million potential customers, or "POPs." The company has been at the forefront of joint cellular industry initiatives to maximize the potential of cellular radio through seamless, national wireless services. For example, McCaw has been a driving force in the formation of the Cellular One[®], the North American Cellular Network, and the national Data Over Cellular project announced in April of this year. McCaw and its affiliate, LIN Broadcasting Corporation, also have extensive experience in managing mass communications cable television and broadcast television systems, as well as an extensive national telecommunications network billing and administrative infrastructure.

II. DBCS ADDRESSES UNMET DATA COMMUNICATIONS NEEDS

DBCS is a bold response to current problems in how information is used and disseminated in today's society. Although the computer has become an indispensable technology in the information user's quest to process data efficiently, the functionality of computers for both businesses and consumers is limited by the availability of needed data and the utility of the information that is provided to the computer. By creating a data broadcast network, the Petitioners have effectively isolated the characteristics of delivery that users need so that information can be more accessible and productively used.

To date, data interexchange has been almost exclusively the domain of two-way, individual circuits, whether temporary switched circuits or semi-permanent leased circuits. Although there will always be a need for interactive two-way connections, the use of two-way circuits for pure bulk data point-to-multipoint transfer applications is inefficient. However, it is the only solution today because sufficiently reliable one-way communications are not available. In other words, the cost of distributing information to multiple users using a series of point-to-point connections rises linearly with the number of distributees. Furthermore, the price of telecommunications has remained relatively static with only small improvements in throughput, and consequently the costs of data transmission for one-way point-to-multipoint applications are unlikely to decline relative to the growth of information being generated. For DBCS, the costs are fixed whether one user or 10 million receive the data.

To date, the explosion in computing power has not meant an explosion in information management power. Despite the advent of extraordinary computer processing power, data transmission is still in its infancy. The overwhelming majority of business information, for example, still is transmitted on paper.² Several technologies have been deployed to address the worst deficiencies of paper as an information distribution methodology. Until DBCS,

² Somewhat ironically, even information generated on computers is rendered to print format for dissemination. This pleading, for example, was produced as a collaborative effort using word processing software on several different computer systems. However, it has been rendered onto paper for submission to the FCC. Paper persists because of its benefits of relative permanency, ability to be physically shared with others, relatively inexpensive publishing costs, and capacity to communicate virtually any type of information. The timely delivery of printed information, however, depends upon physical transportation of the paper itself. The costs and inconvenience of this paradox are well known.

none of these interim technologies offered a comprehensive solution to the problem of mass information dissemination:

- Facsimile machines, for example, improve the timeliness of information delivery, but do not address the cost-effectiveness of storing, transporting, and publishing extensive libraries of documentary information, nor do they address the user's needs to manipulate data upon receipt, since the tools of automation cannot be used to expedite the search for relevant information.
- CD-ROM technology significantly improves on an information provider's ability to store information in an electronic form, thereby enabling end users to manipulate the data as they see fit. Unfortunately, CD-ROMs are not an economically viable means of data transfer for the great majority of information sources, since complex and expensive technology currently is required to "write" CD-ROMs, although the price of CD-ROM "read" technology is decreasing. Moreover, CD-ROM drives are slow, the devices are read-only, and at approximately 540 MB capacity, they are not significantly greater capacity than many of the magnetic disk drives now available. Even more importantly, CD-ROMs still rely on physical transportation for data transmission, thus limiting the timeliness of the data that can be transferred. This may explain why industry projections for the media have never been realized.
- Online databases were, perhaps, the best solution deployed to date. The database author maintains the timeliness of the data and users can manipulate the data set functionally to retrieve items of interest. Unfortunately, a typical commercial database functions as if the user's computer were no more than a "dumb" terminal. Users generally must initiate access to the data, and thus may not learn about time critical information until after the information has ceased to be useful. In addition, the price of two-way, interactive connections has placed a premium on their usage since every user pays for the entire distribution cost to him even though the data is the same.

DBCS solves these basic problems for users by combining a nationwide point-to-multipoint broadcasting network for the delivery of digitized data with a sophisticated data management system.

DBCS involves a complete rethinking of data transmission fundamentals. Petitioners designed DBCS as a one-way data path that would be reliable enough to obviate the need for

error and flow control signals, thus freeing point-to-multipoint data transfer from the constraints of expensive, circuit-based operations. By enhancing the availability and utility of information, DBCS will provide significant productivity and efficiency benefits for both businesses and consumers, as well as promoting information flow to the information disenfranchised.

III. THE DBCS SYSTEM

A. DBCS SERVICE CAPABILITIES

DBCS offers a complete and inexpensive solution to information age data distribution problems for a wide variety of new data services. First, DBCS is very fast and, under prearranged conditions, the DBCS architecture can distribute information almost instantaneously. Second, the DBCS network configuration allows point-to-multipoint distribution at a very low incremental cost per information receiver. Third, DBCS efficiently transmits the increasingly large volumes of data that are being amassed, and are required for emerging graphical applications and interfaces, as well as existing textual information. As shown in Petitioners' market study (Appendix B), and summarized below, information creators increasingly need these capabilities, individually and collectively, to enhance the utility and accessibility of their data for the information consumer.

Speed. The high speed of the DBCS network is, in itself, a distribution solution necessary for certain time sensitive services. Such services include, for example, news, weather, and financial information distribution services. Some of these services are available

today, but as text-only offerings for premium, "high-end" users, because the lack of a suitable transmission vehicle drives up delivery costs. DBCS, in contrast, could inexpensively transmit a single-spaced ASCII page in less than 3/100ths of a second and thus permit information providers to include, for example, graphical weather maps or newsworthy photographs. Most highly time sensitive data networks, on the other hand, require capacity on demand even for text-only services, and thus rely on permanent networks of leased lines, satellite/FM sideband transmission, or VSAT technology. Not only are the initial fixed costs of these services prohibitive, there also are high recurring costs. Furthermore, since satellite-based technologies typically rely on line of sight transmission, time sensitive data may not be available to all users.

Low Costs and Ubiquity. There also are a number of beneficial emerging services that require economical distribution of information from a single source to a large base of users, including electronic delivery of periodicals, software updates, compound documents, complex documentation, and decentralized database search indices. At the present time, to the extent that these services are offered at all, the delivery mechanisms are quite expensive or very slow. Periodicals, for example, typically travel by mail.³ Software updates generally are transferred on floppy disks retailed through various vendors, a process that is slow and expensive.⁴ And, for those specialized providers who have separated the

³ There are, for example, over 100,000 newsletters in the United States, and 11,000 other periodicals (8,800 of which are non-consumer, non-agricultural). The U.S. Postal Service, in fact, estimates that 10.6 billion pieces of 2nd class mail will travel at a total mailer cost of \$1.91 billion.

⁴ Software updates of top-selling microcomputer products typically have a cost of goods between \$7.00 and \$12.00 per copy. Although development costs will still remain a large expense, DBCS could virtually

(continued...)

processing and retrieval aspects of commercial databases to allow users to perform searches and inquiries on their own computers, information often is transmitted on CD-ROMs, a technology that has been slow to gain public acceptance, requires a special reader costing \$500.00 or more, is slow, read-only, and incapable of dynamic updating — and still must be delivered by mail. For many of these services, delivery adds significantly to the cost of providing the service, and can easily render the service prohibitively expensive. The lack of a ubiquitous delivery system like DBCS thus impedes the growth of a wide range of beneficial information services.

High Capacity. DBCS also offers a high volume "pipeline" — 60 to 75 gigabytes per day using compression techniques — making feasible services relying on economic delivery of large quantities of one-way electronic data. Such services could include, for example, the delivery of the entire daily output of governmental information, the distribution of internal and public business documents, maintenance of specialized multimedia documentation at remote sites, the distribution of books, periodicals, and self-published manuscripts, downloading of data from databases, color graphics applications, remote publication of specialized documentation that must be regularly updated, transmission of data secured using high level encryption routines, and de-archiving from centralized electronic storage banks. These services are not ordinarily available because today's solution to high volume data transfer needs is circuit oriented, requiring inefficient use of two-way access lines. Since the

^{*}(...continued)
eliminate the actual distribution costs and the costs of producing updates in multiple medias (e.g., 3 1/2" and 5 1/4" floppy disks) for different CPUs.

fixed and recurring costs of these lines grows with the data rate, users must either pay high charges for circuit use or live with extremely slow throughput rates.

High circuit costs and low throughput make it impossible, for example, to distribute software updates, a product which runs on computers and therefore should lend itself to electronic distribution. A 5 megabyte software package (excluding documentation) would take almost five hours to transmit to each end user at the widely available 2400 baud speed (not including ACK/NAK packet protocol overhead), and over one hour at 9600 baud. This is unacceptably slow and cumbersome for customers. Moreover, the cost per end user would greatly exceed postal costs. Thus, electronic software distribution by current circuit technology is both less convenient and less economical than shipping. Although the technology is in place to deliver software digitally, these factors explain why it is only done for small game-type programs.

B. THE DBCS SYSTEM ARCHITECTURE

The DBCS network, in a very simplistic sense, can be viewed as a centralized information clearinghouse delivering data to users throughout the nation over a low cost, high speed broadcast superhighway. Information providers -- e.g., news wire services, database services, and publishers -- forward data by various means to a central collection point. This data is rapidly collated and packaged with other sources' data, and distributed throughout the network for dissemination to end users. End users, in turn, receive the information via radio broadcasts and manipulate the information in privately beneficial ways. Thus, DBCS can be broken down functionally into four components: (1) information

transmission to the clearinghouse; (2) distribution and control of information transmission within the network; (3) information transmission from the network to end users; and (4) end user control of transmitted information. Each of these elements is described below.

Information transmission to the DBCS network. Petitioners' have structured the DBCS network to allow information providers the greatest practical degree of flexibility. For example, virtually any electronic information source can interface with the network to provide data for broadcast. Petitioners intend to support links that include specialized gateways (e.g., electronic mail systems or intracorporate networks); dial-up access via modem (e.g., incidental users); and leased data lines from information providers needing regularly scheduled broadcast time slots (e.g., an agricultural weather service or a legal database). Information providers will be required to transmit, or maintain at the central site, a data bank containing the logical addresses of the users or groups for whom the data is targeted. Because the system is very flexible, end user billing arrangements and special data handling routines at the end user's receiver also can be structured as needed.

Petitioners anticipate that DBCS local transmitters will provide wide area coverage not only in major metropolitan areas, but in all but the most remote rural regions.⁵ And, using Omnipoint's unique direct sequence spread spectrum technology and the characteristics of one-way broadcast transmission (e.g., DBCS is a predictable interferer since there are no

⁵ Users in remote areas, however, are not precluded from accessing DBCS. Since the nationwide satellite simulcast is always available in lieu of the locally retransmitted broadcast, any user can access the DBCS network through the use of a VSAT terminal. Importantly, in those regions of the country where broadcast transmission is uneconomic; i.e., low population density agricultural regions, VSAT use is economic and line of sight is always available. In fact, rural agricultural users are among the biggest consumers of VSATs. VSAT recipients of DBCS will still benefit from the wide variety of services available and the convenience of DBCS software.

uncontrolled remote transmitters), these local transmitters will be capable of co-existing with the current OFS microwave users. In addition, with the combination of a simulcast spread spectrum network, DBCS receivers capable of constructive signal summing, and with the absence of capacity constraints limiting the size of DBCS cells, Petitioners have incredible flexibility in transmitter effective radiated power ("ERP"). Thus, Petitioners are able to use extremely high power (e.g., 100+ watts), wide area transmitters in regions where OFS interference concerns are not present and sectorized, low power transmitters (e.g., potentially as low as 100 milliwatts) where interference potential does exist. Accordingly, DBCS is a highly efficient proposed use of spectrum.

Intranetwork distribution and control of information. Utilizing the raw data, logical addresses, and options requested by the information provider, the DBCS carrier prepares the information for transmission over the wireless network. The information provider's data will be addressed and the address information encrypted to ensure providers with control over access by the end user.⁶ Each provider's data are assembled into a stream relying on defined priorities for delivery; i.e., a news source may require an extremely high priority, while a documentation update may be deferred for nighttime or another, non-busy, time for transmission. The data stream will then be compressed and packetized, and forward error detection codes will be added to ensure data integrity. Importantly, all of these tasks are automated and can be accomplished with negligible time lag. Finally, the packet stream will

⁶ Information providers will also have the option of having their data encrypted.

be uplinked to a satellite with national coverage for retransmission to the individual local transmitters that comprise Petitioners' ubiquitous broadcast network.⁷

Information transmission from the network to end users. At each network satellite receive station, a VSAT receives the satellite data stream and rebroadcasts the information terrestrially using a nondestructive spread spectrum technique. Due to the design of Petitioners' spread spectrum network, DBCS transmissions will penetrate interior and exterior walls to provide high quality indoor reception. Each user's receiver monitors the incoming stream from the local transmitter, becoming active only for data destined for that particular address (thus conserving battery power in portable systems). Any packets addressed to the receiver will be separated from the broadcast stream and decoded to verify error free transmission. The data will then be reassembled from the packets and passed to the DBCS Electronic Librarian™ resident in the user's computer.

Since DBCS is designed as a mass communications technology, important design goals included making DBCS receivers small and extremely low cost, while offering data rates fast enough to multiplex a wide variety of services. Using Omnipoint's spread spectrum devices and custom chip technology, DBCS receivers should be small enough to fit even within handheld devices, making DBCS a viable transmission system for portable computer users as well as users at fixed locations. Omnipoint's technology also obviates the need for complex, costly, and power consumptive adaptive equalizers necessary to overcome delay spread induced inter-symbol interference, and thus production DBCS receivers should

⁷ Although VSAT distribution is uneconomic for all individual end users, since Petitioners spread the transmission network costs over a wide user base, VSAT distribution within the network is highly economic.

function in a mobile environment and cost less than \$100.00. This is well within the reach of domestic computer users. In fact, a typical consumer user could easily amortize the cost of a DBCS receiver with one year's local telephone bill.⁸

End user control of transmitted information. The end user's DBCS system will include, in addition to the receiver unit, customized Electronic Librarian™ software for the user's computer to process and store information passed to the computer by the DBCS receiver. The DBCS Electronic Librarian™ generally will be a background task in the processor that will decide what actions should be performed on the data it receives. In the simplest case, the data will be stored and the user alerted to its presence. Using a DBCS application program, the user could then, among other things, preview the information, read the information once, delete the information, or republish the information locally with varying charges.⁹ For a more complex database application, the DBCS Electronic Librarian™ might automatically perform an index update, modifying information in a search tree resident on the user's computer.¹⁰ The DBCS Electronic Librarian™ also could pass the

⁸ The FCC's Industry Analysis Division has indicated that the average residential user's telephone bill is between \$17.00 and \$18.00 per month, and the average business user's local telephone bill is between \$40.00 and \$45.00 per month.

⁹ As discussed in the system architecture appendix (Exhibit B), certain DBCS functions will require a backhaul network to support administrative and accounting options. Petitioners, using Oracle's considerable experience as a data management company, are creating a billing system that functions on a periodic basis, transmitting data on usage from the end user to the central billing system by landline or other back channel. For example, the user might dump the billing data to a diskette in encrypted form, or have his computer automatically call a regional billing center and send the information over a telephone connection to a network billing computer. DBCS cannot, and is not intended to, eliminate completely the need for interactive connections, but it can significantly minimize the number of transactions that must occur using two-way real time connections.

¹⁰ Instead of maintaining indices at a single central location, news retrieval services could now use DBCS to broadcast their index daily, allow local off-line searches, and then deliver the data requested with far lower costs and greater efficiency than their current on-line system.

data through an end user-defined filter to screen for information that triggers software alarms. For example, a user could subscribe to a general news wire service and request to be notified about articles using certain key words like "telecommunications" or "PCS." Thus, DBCS is not merely a conduit for information, but rather a comprehensive data management system for information providers, and a central source for the very wide variety of information services needing speed, capacity, and reliability.

**C. DBCS CAN BE IMPLEMENTED WITH A SHARED ALLOCATION
OF 10 MHZ IN THE EMERGING TECHNOLOGIES BAND**

Petitioners have requested a transmission bandwidth of 10 MHz for DBCS implementation.¹¹ This bandwidth, which is consistent with the current OFS channelization policies, allows for robust multiple signal combining and ultimately provides for up to 1.5 Mbit/s wireless data broadcasting rates. In comparison, narrower bandwidth systems would cause significantly greater interference to an incumbent OFS user and would therefore require exclusion zones that would make DBCS impractical. For example, a 500 kHz system operating *outside* the OFS beam path at just 100 milliwatts would still require up to a 35 mile exclusion zone. Omnipoint's system at 100 milliwatts requires only a 5 mile exclusion zone assuming worst case free space propagation and the requirement not to raise the OFS noise floor by more than 1 dB.¹²

¹¹ Importantly, 10 MHz constitutes a minimum spectrum allocation for DBCS, but the FCC should recognize that the system could provide significantly higher data rates if more contiguous spectrum were to be made available.

¹² Most real world situations will allow Omnipoint to operate significantly closer.

Petitioners believe that DBCS spectrum needs can be satisfied using the bands the Commission recently proposed to reallocate in the 2 GHz band for use by "emerging technologies."¹³ The Commission also proposed measures to relocate the existing fixed microwave users of the band. For the technical reasons noted *supra*, Petitioners submit that DBCS is suited ideally for deployment in the emerging technologies band since the dislocation effects of DBCS on existing OFS users are insignificant in comparison to other services. Not only is DBCS the type of service the Commission is seeking to promote,¹⁴ the electrical interference characteristics of the emerging technologies band will allow DBCS to "share" spectrum with existing users, thereby minimizing the impact of new technology development.

Significantly, the use of spread spectrum for DBCS also provides a mechanism for introducing competition. Because separate orthogonal pseudo-noise ("PN") codes could be assigned to different providers to operate CDMA systems on the same 10 MHz band, more than one licensee can be accommodated on the same bandwidth.¹⁵ Notwithstanding CDMA sharing, the band has a finite capacity and unlimited entry is not possible. In other words,

¹³ *In the Matter of Redevelopment of Spectrum to Encourage Innovation in the Use of New Telecommunications Technologies*, ET Docket No. 92-9 (February 7, 1992).

¹⁴ DBCS is a technically innovative new service appropriate for licensing as an emerging technology. In the Commission *Emerging Technologies NPRM*, it indicated that "frequencies in the emerging technologies band would be intended primarily for use by new services made possible through technological advances." *Id.* at ¶ 28. Accordingly, the FCC stated that "requests for operation of new services in these bands should demonstrate that the service makes innovative use of a new technology and that the technology is most appropriately suited to operate [in] the 2 GHz region." *Id.* As shown in Sections IV and V, *infra*, DBCS meets these requirements.

¹⁵ Even with spread spectrum operation, two or more DBCS providers utilizing the same band would be required to co-locate transmitters and to share the technology for DBCS operation in order to guarantee that PN codes would be orthogonal. Petitioners are continuing to experiment with other possible competitive arrangements that would permit full facilities-based competition.

each additional spread spectrum system licensed in the same band will raise the threshold elevation of OFS receivers and lower the signal to noise ratio for DBCS receivers. At some point, the ambient noise in the band will overwhelm existing systems, and, in any event, will necessitate higher power or lower data rate operation.

IV. DBCS IS AN INNOVATIVE AND EFFICIENT DATA TRANSMISSION SERVICE WARRANTING GRANT OF A PIONEER'S PREFERENCE

A. PETITIONERS HAVE DEVELOPED SPREAD SPECTRUM TECHNICAL INNOVATIONS TO IMPLEMENT THE DBCS SERVICE

The Commission promulgated strict standards for the award of licensing preferences in the *Pioneer Preference Order*.¹⁶ In particular, the Commission indicated that it would grant pioneer's preferences only to applicants that have invested significant efforts to develop a new or enhanced service,¹⁷ stating a pioneer must "demonstrat[e] that it . . . has developed an innovative proposal that leads to the establishment of a service not currently provided or a substantial enhancement of an existing service."¹⁸ In this context, an "innovative proposal" means:

[T]he petitioner . . . has brought out the capabilities or possibilities of the technology or service or has brought them to a more advanced or effective state. Generally we believe that an innovation could be an added functionality, a different use of the spectrum than previously available, or a change in the operating or technical characteristics of a

¹⁶ *Establishment of Procedures to Provide a Preference to Applicants Proposing an Allocation for New Services*, 6 FCC Rcd at 3488 (1991) [*"Pioneer Preference Order"*], recon. FCC 92-57 (rel. February 26, 1992).

¹⁷ *Pioneer Preference Order*, 6 FCC Rcd at 3494 n.10.

¹⁸ *Pioneer Preference Order*, 6 FCC Rcd at 3494.

service, any of which involve a substantial change from that which existed prior to the time the preference is requested.¹⁹

The Commission also listed a number of potential indicia of new or enhanced services:

[A]n added functionality provided to a broader group of customers than was previously available or a new technology that permits 1) increased ability to perform an existing work requirement; 2) increased capacity in an existing service; 3) a substantial cost reduction in an existing service; 4) improved quality of an existing service.²⁰

As shown below, Petitioners' DBCS implementation satisfies the FCC's stringent standards for award of a pioneer's preference.

Specifically, Petitioners have incorporated a number of technical advances into two innovations that make DBCS possible. First, Omnipoint's development of extremely high performance direct sequence spread spectrum receivers has opened the door to creating a consumer-oriented, reliable, wide area, and high speed data broadcast network. Second, the combination of several advanced technologies allow DBCS to be integrated with existing spectrum licensees operating OFS microwave stations, permitting DBCS to be implemented without displacing other valuable spectrum uses. Petitioners submit that these innovations warrant a pioneer's preference.

¹⁹ *Id.*

²⁰ *Id.*

1. **DBCS's Use of Advanced Technology In Providing Low-Cost, High Speed, High Volume and Wide Area Data Broadcasts Is Unlike Any Existing Or Proposed Service**

Petitioners' DBCS system is unlike any service implemented or proposed to date.

DBCS provides wide area distribution of one-way data at nominal data rates of up to 1.5 Mbit/s to low cost, low power receivers – a substantial technical achievement. Omnipoint's spread spectrum system provides several major pioneering innovations that enable such an extraordinarily high data rate to be delivered to low cost stationary and mobile receivers:

- Traditional RF digital simulcast broadcast techniques have been limited to low data rates (*i.e.*, under 24 kbit/s) or very short ranges (*i.e.*, a few hundred feet at 500 kbit/s) due to the need for impractically expensive and power consumptive adaptive equalizers to overcome delay spread induced inter-symbol interference ("ISI").
- Traditional techniques cannot allow for low cost receivers to receive *multiple simultaneous* signals up to 1.5 Mbit/s in order to provide continuous overlapping coverage. Paging simulcasts are currently done at 1200 baud and the state of the art in theory for FM techniques is 3000 baud. VBI broadcasts operate at approximately 9600 kbit/s and the fastest FM subcarrier broadcasters reach speeds of 20 kbit/s, with contemplated improvements allowing perhaps 64 kbit/s. This speed is below the throughput requirements of many individual services, and cannot support a wide variety of data-rich or graphical services. VSAT can, of course, provide sufficient speed, but without in-building coverage and at considerable installation cost and complexity not economic for most end users and applications in urban areas.

DBCS uses a multiple signal combining spread spectrum system that sums the energy from multiple paths, eliminating the need for complex cell site planning and complex continuous frequency scanning receivers. In addition, Omnipoint's spread spectrum system overcomes cell boundary problems (*e.g.*, hand-off or jamming), and, in fact, turns it into an advantage (*i.e.*, complete coverage at low cost).

Although point-to-multipoint radio services do exist, e.g., the Digital Electronic Messaging Service or VSAT distribution, no other radio based technology provides the cost and coverage characteristics of DBCS. In fact, none of the existing vehicles for point-to-multipoint transmission even purport to be consumer technologies. DBCS provides not only "a substantial cost reduction" for consumers, but also high speed and high volume transfer capability — an "increased ability to perform an existing work requirement." Thus, DBCS is "a different use of the spectrum than previously available" within the meaning of the *Pioneer's Preference Order*. Further, DBCS represents an enormous advance in the "speed or quality of information transfer" that "significantly reduce[s] costs to the public," and thus should be given "careful consideration [for a pioneer's preference]."²¹

2. Petitioners Have Developed Efficient Technologies That Capitalize on Data Broadcast Characteristics To Allow the DBCS System To Share With Existing OFS Users

After considerable laboratory investigation, computer modelling, and field testing under Omnipoint's experimental license, Petitioners already have made substantial progress in validating a DBCS system capable of coexistence with existing OFS users. The final phase of Petitioners' testing will culminate in the near future when a prototype data broadcast system is implemented in Colorado Springs, Colorado. Petitioners have a high degree of confidence that these tests will prove out DBCS technology, since, as shown in Exhibit A, extensive work already has been done to demonstrate DBCS's sharing ability.

²¹ *Id.*

DBCS's ability to coexist in the current OFS band is the result of low power direct sequence spread spectrum equipment specially developed by Omnipoint to take advantage of the following characteristics of DBCS:

- **Channelization.** DBCS utilizes a 10 MHz contiguous band of spectrum consistent with the existing channelization of the band (*i.e.*, 94 percent of all OFS links in this band are 10 MHz links);
- **Predictability.** Unlike two-way systems, DBCS is predictable as a potential interferer because *there are no remote transmitters causing uncontrolled interference*; and,
- **Orientation.** Since DBCS transmitter sites are fixed, the antenna orientation is known and DBCS can make use of orthogonally polarized antennas.

In order to minimize impact on OFS operations, Petitioners have designed spread spectrum equipment capitalizing on these factors, which feature:

- **Extremely Low Potential for Interference to OFS.** Omnipoint's direct sequence spread spectrum system provides low spectral density for coexistence. In actual practice, when transmitting in the direction of a co-channel OFS receiver, an exclusion zone invariably must be established. The required exclusion range is a function of transmit effective radiated power ("ERP"), signal bandwidth, and the allowable apparent noise figure of the OFS receiver, referred to as threshold elevation. Because DBCS uses a noise-like, spread spectrum signal, the effect of DBCS transmissions on OFS merely increases the threshold elevation. For a given transmit ERP, Petitioners' 10 MHz bandwidth signal results in 1/100 (20 dB) less interference to an OFS receiver compared with a similar power, 100 kHz bandwidth signal. *Translated into range, DBCS transmit stations can be a factor of ten times closer to a typical analog OFS receiving station than a narrowband transmitter.*
- **Signal Robustness.** Omnipoint's spread spectrum system introduces noncoherent detection and reception of multiple simultaneous signals. This provides DBCS with reduced sensitivity to multipath and a mechanism for combining three way data transmissions. DBCS's overlapping coverage and the receiver's ability to combine up to three signals has a number of significant benefits: (1) sensitivity to signal shadowing effects caused by buildings, hills, and other terrain considerations is considerably reduced; (2) multipath fading

effects are mitigated and error correction coding performance is enhanced; (3) triple transmission provides space diversity; and, (4) spread spectrum provides frequency diversity.

- *Low Transmit Power.* The DBCS network utilizes sectorized transmissions to avoid jamming OFS receivers. To maximize deployment flexibility, DBCS is designed to permit all sectors and transmitters to operate at the same frequency. Petitioners' technical appendix shows that even areas near an OFS user on the same frequency, a triangular grid of transmitters 1 to 2 km apart provides 600 kbit/s raw data rate. Since, in any given area, the DBCS receiver will be in range of up to three base stations, Omnipoint's hand held direct sequence spread spectrum technology permits radical reductions in transmission power.

All of the above factors combine to reduce the potential for interference to OFS licensees.

While no existing co-channel technology can guarantee complete overlay coverage without interference, the exclusion zones for DBCS are so much smaller than for other systems that DBCS can be commercially deployed without significant disruption of existing users.

The Commission has stated that "technologies that yield efficiencies in spectrum use . . . or spectrum sharing . . . will be given careful consideration [for a pioneer's preference]."²² By allowing DBCS to be deployed on channels already occupied by OFS fixed microwave users, Petitioners' technology is a radical advance in spectrum efficiency that warrants grant of a pioneer's preference.

B. DBCS IS INHERENTLY NATIONWIDE IN SCOPE

DBCS has the potential to expand greatly the information service options available in the U.S. market. However, for technical and market reasons, DBCS is inherently

²² *Id.*

nationwide in scope and cannot viably be offered on a smaller scale. First, the fundamental concept behind DBCS is centralized collection and national distribution of information. In order to accomplish this feat, full CONUS satellite delivery to individual transmitters is the only suitable intranetwork transport system. Creating a network of T-1 circuits to individual transmitters spaced, in places, at less than 5 miles, would be prohibitively expensive and provide lower reliability. Thus, DBCS's technical foundation relies on a national transmission system and DBCS providers should be issued nationwide licenses.

Second, DBCS is characterized economically by high initial infrastructure costs, high fixed overhead costs, and virtually nonexistent incremental costs for additional subscribers. This is true for both the broadcaster and the information provider, and has a direct impact on the Petitioners' ability to attract providers to the service. In other words, in order to recover fixed costs, Petitioners must amortize the large infrastructure and overhead costs over an extremely large customer base. Although the same theory is true to some extent for all radio services, the extreme disparity between fixed and variable costs for DBCS compels national licensing.

Third, without the capability to achieve nationwide distribution for its data product, an information provider must maintain dual distribution channels. Since most existing data and computer marketing is conducted on a nationwide basis, any market divisions imposed by regulation would require information providers to maintain two distribution infrastructures. Generally, information providers' costs per subscriber will be defined by the most expensive distribution method, and thus multiple market divisions for DBCS will negate the bulk of DBCS's low cost benefits. Moreover, many niche services which serve a

particular social or business need, for example agriculture or science, can only obtain an adequate community of interest from a national base. Thus, if DBCS is not licensed on a national level, many of the contemplated new services may not emerge.

Finally, DBCS end users' data needs are not categorically confined to localities or regions, but are nationwide. The ability to access data from local providers, in fact, generally represents market segments where the impact of DBCS will not be felt as significantly, since as the cost of distribution decreases, and the available means of distribution increases, the closer the information source gets to the end user. DBCS will only achieve its highest potential benefits for users if the network allows data users to access information on a nonspecific geographic basis.

Petitioners are sensitive to the Commission's predisposition to only award national pioneer preferences where fully justified and under conditions that ensure competitive entry. For technical, operational, and economic reasons, DBCS can and should be considered a national service. Most fundamentally, national coverage is essential to meet the needs of information service providers serving customers across the country. National coverage also is necessary to take full advantage of the efficiencies of mass distribution contemplated in this proposal. In addition, the direct sequence spread spectrum innovations associated with DBCS will permit multiple competing licensees utilizing the same 10 MHz spectrum, if carefully coordinated, or if the Commission determines an additional 10 MHz band should be allocated to DBCS. Accordingly, Petitioners respectfully request a national pioneer preference for DBCS.

C. DBCS WILL PROVIDE SIGNIFICANT PUBLIC BENEFITS

It is a truism that business runs on information. Our competitiveness as a nation depends upon each individual's ability to assimilate, manage, and leverage a rapidly expanding base of information. The four keys to accomplishing this task are: (1) accessibility, or the ability to obtain necessary information; (2) timeliness, or the ability to receive up-to-date information; (3) functionality, or the ability to manipulate and extract useful data from a larger pool of information; and (4) cost efficiency, or the ability to perform the information processing tasks inexpensively. DBCS offers an unparalleled scheme for providing the information user with each of these keys.

Importantly, however, DBCS is not simply a big business service. Since broadcasting is unmatched as a medium of mass communication, new small business, educational, and consumer users can be added at a minimal incremental cost to the DBCS provider. DBCS receivers are targeted to cost under \$100.00, making DBCS a technology accessible to the majority of America. The DBCS user base can easily be extended from beyond the business world to consumers, educational users, rural users, and governmental users without additional infrastructure costs. Indeed, it is these "information poor" users that may gain the most from DBCS deployment, since serving these consumer markets can be accomplished on a highly cost-effective basis relative to these users' ability to pay. In contrast, today database subscribership is peaking, and industry analysts have concluded that such services are reaching maximal market penetration under the current data transmission infrastructure.

Petitioners' unique DBCS network architecture, in addition to providing low-cost ubiquitous coverage, allows information vendors controlled end user access. Since access to data can be regulated, the pricing of information itself can be structured to increase the availability of the information to a wider consumer base. For example, a news wire service could charge a premium for minute by minute coverage, but offer an hour by hour service to the general public and schools. Because the data has already been archived, offering the secondary service costs the information provider virtually nothing, can be provided at a nominal charge, and thus promotes increased availability of useful data for the public as a whole. Similarly, since the services provided can be user-specific, information providers could create preferential pricing policies for public institutions like libraries, schools, or government institutions. Thus, DBCS is an enabling technology that promotes data transmission for the vast portions of the population that are information disenfranchised.

V. CONCLUSION

In adopting its pioneer preference policies, the Commission has sought to encourage innovation, promote efficient use of spectrum, and hasten the advent of important new wireless services to the public. In choosing "tentative selectees" for such preferences, the Commission also has focused upon the technical feasibility of bringing the concept into reality and the extent to which the requestors have committed substantial resources toward that objective. On all counts, the DBCS service and its proponents meet these strict criteria.

DBCS will bring the exciting potential of innovative, direct sequence spread spectrum technology to the public. Spectrum efficiency would be maximized to an unprecedented level

by allowing new data broadcast service providers to use a modest 10 MHz of spectrum on a shared basis with incumbent 1850-1990 MHz licensees. The resulting service would provide for the first time a digital data superhighway that spans the country and extends the capabilities of advanced computing to all segments of society.

Petitioners' principals have already invested substantial resources and expertise in evolving the concept into reality. Work already undertaken confirms the basic feasibility of the system. Tests about to be undertaken will soon verify its full capabilities. Indeed, three major corporations with well recognized capabilities (Omnipoint, Oracle, and McCaw) have combined their technological, marketing, and economic strengths to ensure that the allocation of spectrum will be promptly followed by the deployment of a viable and important new service.

APPENDIX A

TECHNICAL DESCRIPTION OF DBCS INNOVATIONS

The DBCS system provides wide area distribution of one-way data at nominal data rates of up to 1.5 million bits per second ("Mbit/s") to low cost, low power receivers with minimal disturbance to the existing Operational Fixed Services ("OFS") users in the 1850-1990 MHz band. In order to achieve this performance, DBCS relies on two innovations that combine a number of advanced technologies:

- DBCS mobiles are compact, inexpensive, and capable of receiving multiple simultaneous low power 1.5 Mbit/s transmissions.
- The DBCS network transmission system can share a 10 MHz band with existing OFS users without causing interference to microwave stations or creating significant exclusion zones.

Each of these innovations, representing a vast increase in the state of the art, is described in further detail below.

I. DBCS RECEIVER TECHNOLOGY

Petitioners' spread spectrum system DBCS receivers are, in and of themselves, major pioneering innovations. DBCS receivers are the latest evolution of a continuing spread spectrum engineering effort initiated by Omnipoint in 1987 and, with regard to a number of factors, a significant improvement over the current state of the art in RF data transmission:

- *Noncoherent Signal Combining.* DBCS mobiles can receive *multiple simultaneous* high data rate signals in order to provide continuous overlapping coverage.
- *Increased Speed and Range.* DBCS mobiles provide orders of magnitude improvements over traditional RF digital techniques in terms of data rate and range.

- *Compact Size.* Using a gallium arsenide microchip developed by Omnipoint, DBCS's receivers will be able to be reduced to modems that will fit into handheld devices.
- *Extremely Low Cost.* For production quantities similar to pagers, Petitioners expect DBCS receivers to cost approximately \$100.00.

Omnipoint's spread spectrum receivers are capable of noncoherent detection and reception of multiple simultaneous signals, without the use of impractically expensive and power consumptive adaptive equalizers. In contrast, traditional RF techniques operating without adaptive equalizers experience delay induced inter-symbol interference, which is caused when multiple offset signals arrive at the receiver and combine destructively. Signal offsets can be caused by, among other factors, multipath, shadowing, or multiple transmitter operations. Inter-symbol interference thus limits traditional RF techniques without equalizers to low speed (*i.e.*, 50 kbit/s), or short range (*i.e.*, several hundred feet), or non-simulcast operation (*e.g.*, traditional simulcasting techniques for continuous coverage are theoretically limited to 3000 baud/s).

Capitalizing on the ability of DBCS receiver to combine signals, Petitioners have been able to deploy DBCS as a simulcast (*i.e.*, $n = 1$ reuse) system, and to use sectorized antennas that will provide three usable signals that will be summed by any given mobile. Under these conditions, as shown in Figs. 16-1 to 16-4, data rates up to 1.5 Mbit/s are achievable at relatively long distances. For example, using a transmitter height 100 feet AGL, assuming receivers at 6 feet AGL, and using 100,000 Watt transmitters, which could be deployed in areas without nearby OFS users, a data rate of 1 Mbit/s is possible even with transmitter spacing over 9 kilometers. In areas closer to OFS fixed operations, transmitter power must

be decreased to 1.000 Watt or lower, but data rates of 1 Mbit/s are nevertheless achievable at 1.000 Watt with transmitter spacing slightly over 2.5 kilometers.

Because Omnipoint's combining spread spectrum system is able to sum the energy from three paths, complex cell site planning and complex continuous frequency scanning receivers are unnecessary. In addition, Omnipoint's spread spectrum system overcomes the cell boundary problem (*e.g.*, hand-off or jamming), and, in fact, turns it into an advantage (*i.e.*, complete coverage at low cost).

These features of the DBCS system are derived from the use of Omnipoint's mature direct sequence spread spectrum technology. Unlike many other many other proposals utilizing spread spectrum technology, the technology for DBCS receivers exists -- Omnipoint demonstrated extremely low powered, frequency agile, spread spectrum phone prototypes in 1989, and has had years to improve upon its technology. Using a gallium arsenide integrated receiver and patented or patent-pending techniques, Omnipoint has developed, and is already supplying, a palm-sized spread spectrum data modem. This technology will be further built upon for DBCS and Petitioners will be able to mass produce small and inexpensive direct sequence spread spectrum DBCS receiver units for consumer use.

II. DBCS SPREAD SPECTRUM SHARING

Petitioners' unique, low power, direct sequence spread spectrum system is based on work initiated by Omnipoint five years ago. After considerable laboratory investigation, computer modelling, and preliminary field testing under Omnipoint's existing experimental license, Omnipoint has made substantial progress in validating a DBCS system capable of

coexistence with existing OFS users. DBCS's ability to coexist in the current OFS band is the result of:

- *Low Spectral Energy Density.* Omnipoint's direct sequence spread spectrum system provides low spectral density for coexistence.
- *Triple Overlapping Coverage.* Omnipoint's spread spectrum receivers have reduced sensitivity to multipath, and thus allow three way data transmission combining using sectorized transmissions.
- *Channelization.* DBCS utilizes a 10 MHz contiguous band of spectrum consistent with the existing channelization of the band.
- *DBCS Transmitter Determinism.* DBCS is a predictable potential interferer because there are no remote transmitters causing uncontrolled interference. In addition, because DBCS transmitter sites are fixed, and thus can be oriented to use orthogonally polarized antennas.
- *Graceful Expansion.* DBCS's architecture will permit the system to accommodate higher power, wider area, and higher data rate operations if OFS sharers can be voluntarily migrated to other bands.

Petitioners recognized from the outset that DBCS will have to coexist with current OFS users, and thus employed technology specifically engineered to have minimal impact on OFS operations.

Low spectral energy density emissions provide more compatible operation. In actual practice, when transmitting in the direction of a co-channel OFS receiver, an exclusion zone invariably must be established. The required exclusion range is a function of transmit effective radiated power ("ERP"), signal bandwidth, and allowable apparent noise figure of the OFS receiver, known as the threshold elevation. Because DBCS uses a noise-like, spread spectrum signal, the effect of DBCS transmissions on OFS merely increases the threshold elevation (i.e., has the effect of reducing ES/No). As shown graphically in *Fig. 16-5* for a given transmit ERP, Petitioners' 10 MHz bandwidth signal results in 1/100 (20 dB) less

interference to an OFS receiver compared with a similar power, 100 kHz bandwidth signal. Translated into range, DBCS transmit stations can be a factor of *ten times closer* to a typical analog OFS receiving station.

The governing standard for OFS interference (TSB10-E) requires no more than 1 dB of threshold degradation. Referring to *Fig. 16-1*, a five mile exclusion zone is needed for a 0.100 Watt ERP transmissions towards the OFS receiver when using the same frequency. Relaxing the threshold elevation standard to 6 dB, a 0.100 Watt transmitter requires an exclusion zone of 2.3 miles. Thus, while DBCS can operate within the constraints of TSB10-E, significant improvements could be gained if the threshold elevation of the OFS receivers can be relaxed. This, in fact, may be possible to negotiate on a voluntary basis with existing OFS users, taking advantage of the extensive fade margin of many OFS systems. A tolerance of 30 dB fade margin instead of a 60 dB fade margin (which is common in many actual OFS systems),¹ coupled with a lower DBCS antenna height, cross polarization, lower power, and a lower data rate in that sector may provide for nearly complete coexistence for all practical purposes even on the same frequency as the OFS user.²

Triple overlapping coverage enhances operation and protects OFS users. Because DBCS receivers can sum the energy from multiple signals, the DBCS broadcast network can

¹ For example, Houston represents the most densely populated OFS area of the major MSAs. A COMSEARCH study presented on April 14, 1992 to the Telocator T&E Committee of all Houston OFS links showed average fade margins of 54.4 dB. This corresponds to a mean outage time of 9 seconds per year for a 20 mile link. A 6 dB threshold elevation would lower fade margin to 48.4 dB; outage time increases to 25 seconds per year.

² This is especially true for a data broadcast service since the probable location of the non-urban OFS tower is likely to be in an area without DBCS customers.

use more than one transmitter to provide coverage for a single point using the same frequency band, which has a number of salutary effects for sharing and operation.³ Each transmitter site uses 3 sector antennas and the transmitter sites are laid out in a triangular grid. Thus, in any given area, the DBCS receiver will be in range of at least three base stations. The overlapping coverage and ability to combine three signals:

- Significantly reduces sensitivity to signal shadowing effects caused by buildings, hills, and other terrain considerations.
- Mitigates multipath fading effects and enhances error correction coding performance.
- Triple transmission provides space diversity.
- Spread spectrum provides frequency diversity.

All of the above factors act in combination to reduce significantly required transmit power, and hence the potential for OFS interference.

Fig. 16-1 depicts maximum data rate as a function of base station separation for 3 signal combining assuming receivers are located 6 feet above ground level ("AGL"). The 0.100 Watt ERP sectorized transmission antennas are located 100 feet AGL. When base stations are close together, data rate is dominated by mutual interference considerations while at wider separations, the system is noise limited. Even areas near an OFS user on the same frequency, a triangular grid of transmitters 1 to 2 km apart provides 600 kbit/s raw data rate at a bit error rate ("BER") of 10^{-6} . This figure provides an effective user bit error rate ("UBER") of 10^{-10} . For transmitters extremely close to OFS stations, interference

³ Figure __ compares the effects of mutual interference within a 3 combining system. The receiver is located in the fringe transmission area for the cell, yielding a worst case scenario for co-channel interference. A Hata, large city suburban model is used to estimate path loss from sector transmitters to mobile units.

considerations may require the use of 60 degree cell sectorization and, in the worst case, negotiated relocation of the user or negotiated changes to the threshold elevation of the OFS receiver.

DBCS channelization is comparable with OFS operations. Petitioners have requested a transmission bandwidth of 10 MHz for DBCS implementation. This bandwidth, which is consistent with the current OFS channelization policies, allows for more robust multiple signal combining and ultimately provides for up to 1.5 Mbit/s wireless data broadcasting rates. In comparison, narrower bandwidth systems would cause significantly greater interference to an incumbent OFS user and would therefore require exclusion zones that would make DBCS impractical. As shown in *Fig. 16-6*, for example, a 500 kHz system operating outside the OFS beam path at just 100 milliwatts would still require up to a 35 mile exclusion zone. Omnipoint's system at 100 milliwatts requires only a 5 mile exclusion zone assuming worst case free space propagation and the requirement not to raise the OFS noise floor by more than 1 dB. As described, however, more realistic assumptions will allow Omnipoint to operate significantly closer in most real world situations.

The determinism inherent in DBCS provides additional protection. Unlike two-way systems proposed for the 1850-1990 MHz band, DBCS can take advantage of the fixed placement of all transmitters. As an initial matter, the absence of mobile transmitters means that interference for a DBCS network is entirely deterministic, and can be predicted for any proposed system configuration. In other words, in the absence of unpredictable mobile transmitters that could move within feet, or even hundreds of feet, of an OFS receiver, DBCS interference can be calculated *a priori*. In addition, because DBCS uses only fixed

transmitters, DBCS can take advantage of polarization to provide additional protection to fixed OFS users. Since two-way systems cannot control the orientation of the mobile transmitters, this effect is unique to one-way systems.

DBCS can gracefully expand if voluntary migration can be negotiated. DBCS has been designed to initiate operation at lower data rates than practically achievable by employing low power transmitters. If unshared spectrum can be obtained through the policies which the FCC, the NTIA, and the OFS industry are negotiating, the effective data rate for DBCS can be increased substantially. Should the opportunity arise to migrate just one OFS user to a frequency outside the 1850-1990 MHz band, thereby providing an unshared 10 MHz channel for DBCS within a city, DBCS can be upgraded automatically to higher data rates providing a natural expansion path for the service.

In other words, Petitioners may initially trade off average cell spacing against data rate and coexistence requirements. For early service offerings, Petitioners may choose a lower data rate with wider base station separations. As demand grows, more base stations can be added to the network in a cell splitting arrangement. Alternatively, if just one 10 MHz OFS link can be migrated to an alternative band, Petitioners can increase transmit power to obtain up to 1.5 Mbit/s of raw data transmission rates. Figures 2 - 4 document increased base station separations achievable by raising ERP to 0.500, 1.000, and 100.000 Watts respectively. Peak data rates at close separations are not affected since performance is S/I limited in these regions.

Single frequency operation, *i.e.*, using an $N=1$ re-use pattern, provides an elegantly simple high speed simulcast system, and is possible because of Omnipoint's spread spectrum

system. The system avoids all frequency handoff issues as the user moves from cell to cell and provides for the reception of extraordinary data rates (1000 times faster than existing paging systems) in receiver which will be comparable in cost (e.g., eventually targeted for a manufacturing cost of \$100.00 in similar volumes to those of historical pager sales).

III. CONCLUSION

Thus, Petitioners have designed an advanced DBCS network with the capability of providing wide area distribution of one-way data at data rates of up to 1.5 Mbit/s to low cost, low power receivers. And, as importantly, the system design incorporates advanced technologies to permit the DBCS system to coexist with minimal disturbance to the existing OFS users in the 1850-1990 MHz band. These accomplishments represent a significant advance in the state of the radio art.

APPENDIX B NETWORK ARCHITECTURE

I. SUMMARY

The architecture of DBCS, as envisioned by Petitioners, encompasses several important concepts which taken together provide true innovation in the functional capability to deliver a wide range of digital information, accessible to users in a range of media (text, graphics, images), from a large number of information providers with a variety of distribution needs. As discussed earlier, Petitioners have assessed the needs of these data distributors and their customers and have used these needs in developing the system architecture. The common denominator for these information providers is to distribute their data to a number of users, *i.e.*, point-to-multipoint distribution. Additionally, they have a range of needs in the areas of pricing, administrative control, security considerations, level of data integrity, and level of imperative in immediacy of delivery.

Therefore, the key element in the Petitioners' configuration is the concept of a one-way broadcast network, which is a highly efficient data distributor, supported by a number of systems/components which provide a high level of flexibility in meeting the needs of the data vendor and the end-user.

A. OVERVIEW OF INFORMATION FLOW

As shown in Figure 1, DBCS information flow is conceptually quite simple. A company wishing to distribute its information delivers digitized information and a list of recipients. Petitioners combine the company's data with the data from other information

providers at a central site. The data is addressed, encrypted and compressed. Then it is sent in a packetized stream via satellite or another economical medium to receiving sites in at least 100 major markets nationwide.¹

In each market, the data is re-transmitted via tower-based spread spectrum techniques broadcasting at very high speeds to individual, end-user receivers at customer sites. These receivers are small, very low-cost, individually addressable units of a proprietary design. The receiver may be a board in a personal computer or it may be on or part of a Local Area Network ("LAN") server. It can also be integrated directly into a small handheld display device, portable computer, or, in fact, almost any digital appliance.

The receiver decrypts and decompresses the data and presents it in a processable format to the user's computing device. The DBCS Electronic Librarian™ could then automatically route the data as an "update" to an existing "library" of information, present it to the user (or users) for review or action, or deliver it to one or more mailboxes on a LAN. The encrypted archiving system can support user polling and a wide variety of billing options.

B. KEY CONCEPTS

Four attributes of the system embody its uniqueness (innovation). They are:

- *DBCS's structure as a one way broadcast network.* This topology is very efficient as a mechanism to distribute large volumes of data and conserve scarce spectrum resources.

¹ Users in areas not covered by these sites can be served by VSAT installations. Due to the low probability of line of site or siting acquisition problems, it is anticipated that rural users could install receiving equipment relatively inexpensively.

- *DBCS's ability to offer vendors a variety of options for timing of delivery.* The and determinism of arrival can be adjusted from "immediate" to "delayed" within contracted time frames. Information vendors have varied needs in terms of the relationship of immediacy of delivery to the value of the information. For example, stock price information, on which traders are relying to trade in markets worldwide, needs to have a guarantee of instantaneously delivery. However, software upgrades will be perceived as being delivered in real time if delivered within a few days. Vendors will be able to choose among a number of options for both time frame delivery and guarantee, with appropriate pricing.
- *DBCS's system of distributed administrative control.* Vendors will be able to select from a variety of options for allowing users authorization to receive their information. These options will support the vendor who wishes to provide potential customers with the capability to make an impulse purchase by allowing the user's terminal to authorize access. It will also support the vendor who wishes to screen a potential customer for authority to access the information, a credit check, or require pre-payment before any authorization is made.²
- *DBCS's multiple levels of system security.* This will insure data integrity and prevent unauthorized access. The components which make up the security system include the way in which the data will be assembled for transmission, the spread spectrum technology itself, the proprietary design of the terminal units, and the encryption of the message header. The encryption scheme can use a proprietary methodology with results equal to or exceeding those of a DES Key encryption system. Information providers will have the option of having their entire message encrypted.

² A good analogy of this process is the credit card authorization scheme, where the dollar value of the charge and the merchant's willingness to take on some of the risk sets up an approval process. A ten dollar charge for a can of paint may be authorized without any contact with the processing center, but the purchase of an expensive stereo may require contact through the processing center to the actual card issuing bank.

II. FUNCTIONAL DESCRIPTION OF NETWORK COMPONENTS

A. DATA COLLECTION

Petitioners will employ data collection centers distributed nationwide to optimize communication with and to act as an interface to information vendors. Data collected at the centers will be then delivered to the main center for final compilation into the data stream.

1. Regional Data Collection Centers

Petitioners will maintain regional vendor interface centers across the country. In addition to providing local customer support and technical assistance, these centers will perform a number of other processing functions:

- Regional centers have the ability to accept data on a variety of media, including electronic transmission on dedicated or dial up lines, mag tape, or CD-ROMs.
- Regional centers will maintain subscriber records for vendors.
- Regional centers act as an authorization point for new users.
- Regional centers provide information sources with complete output vendor accounting information on the vendors' choice of media.
- If requested, regional centers encrypt vendor information.

In short, the regional centers are a complete interface to information vendors, obtaining all information necessary to output a data stream to the National Collection Center. As an integral link in the DBCS network, regional centers will have redundant hardware to insure adequate backup capabilities.

2. Main National Collection Center

Petitioners' main collection center essentially acts as an aggregator, collecting the individual feeds from the regional collection centers and integrating them into a single stream. In order to accomplish this, the national collection center must perform all of the functions of the regional centers and, in addition, a variety of other functions:

- The national collection center will prioritize all incoming feeds for appropriate scheduling and to meet delivery guarantees.
- The national collection center will hold a user profiles containing the subscription and authorization levels set by vendors.
- The national collection center will combine the various feeds into a data stream, encrypt the header information, and compress the stream.
- The national collection center will be responsible for archiving vendor's information.

Like the regional centers, the national collection center will have redundant hardware to insure adequate backup capabilities in the event of primary system failure.

B. DATA TRANSMISSION

1. Satellite Transmission

The primary data stream will be uplinked to a satellite for transmission to the Terrestrial Translators (and individual VSAT receivers). Petitioners will minimally employ a secondary link to the terrestrial translators to provide redundancy in transmission. This could be a transponder on a second satellite or, in limited cases, an alternative land line link with high speed data transmission capability (e.g., T-1, T-3, or Frame Relay). The receiving

site will be able to perform redundancy reconciliation to insure the highest degree of data integrity possible.

2. Terrestrial Translators

Terrestrial translating sites in at least 100 metropolitan markets will receive the data stream via a VSAT receiving dish and repeat broadcast the data using the Omnipoint spread spectrum technology described in Appendix A. DBCS terrestrial transmitters will provide complete and redundant coverage of areas with any significant population density. Actual coverage and siting details are dependent, however, upon the OFS use of the spectrum allocated since DBCS can utilize a range of transmitter powers -- and thus provide larger or smaller reliable service areas -- ranging from 100 milliwatts to hundreds of watts.

C. WIRELESS RECEIVERS

Users will receive the data stream via an addressable wireless radio frequency receiver. The wireless receiver employs a proprietary design and will filter the incoming data stream in real time. The receiver will identify and "pick off" those packets identified as destined to its unique, secure address and will be able to decompress and decrypt those packets of broadcast data. The receiver will then create a record of messages received utilizing the packet header information. Importantly, each DBCS receiver is capable of receiving information from a variety of information vendors, *i.e.*, the user can be on multiple

distribution lists. The ability to receive any particular data stream, of course, will be controlled by the access authorizations designated by vendors.³

Using Omnipoint's gallium arsenide technology, DBCS receivers will be small, secure, low-powered units which can interface with the user systems. DBCS receivers can be a card or adapter in an IBM or compatible (ISA, EISA, or MCA bus) computer, Apple Macintosh Nubus, or other computer manufacturer proprietary system. For networks, modified receivers will feed a server or an individual user on a local area network employing Ethernet (Transceiver, Thinnnet, or 10BaseT), Token Ring, Apple Local Talk®, or other computer manufacturer proprietary LAN technology. The connection to the user or server computer can also be through SCSI, serial (RS-422/232), or other computer manufacturer proprietary interfaces. And, since DBCS utilizes small and low power consumption receivers, DBCS receivers can be built into a portables, *e.g.*, a notebook computer, a laptop personal computer, or a single-application discrete device of very small size.

D. USER AGENT SOFTWARE

Petitioners will offer users a powerful user agent software package⁴ to assist in management of the data received. This software package will act as an "Electronic

³ User's will receive notice of the availability of information resources through free announcements on the service or through other direct solicitations. Users could then key in the code of a resource they are interested in receiving and automatically get the next transmission. During the next reconciliation cycle, the receiver would transmit notice of the transaction to the accounting system which would in turn report the new user to the information vendor. Alternatively, the user can order service by telephone or through other agents.

⁴ The software will be generic in functionality across platforms, *e.g.*, personal computers (Macintosh, MS-DOS & Windows, OS/2), minicomputers, workstations (Sun, Apollo, DEC), mainframes, etc. Petitioners will also license the specifications for manufacturers who wish to build proprietary software for the system, and encourage others to design and market software for the system.

Librarian™ — checking data in, routing it to the correct storage space, purging old versions, and alerting users to items which require immediate attention or which may be of interest for browsing. Examples of ways in which the Electronic Librarian™ would function include using tabular data to update a financial profile or a farmer's commodity list; highlighting news stories that discuss an item in a user's field of interest; presenting abstracts of books in the user's field of interest; delivering periodicals, including photographs and advertisements; automatically creating a cross referenced database and bibliographic information on selected stored material; automatically updating stored documentation, thereby negating the need to 'replace sheets' in order to keep manuals complete and up to date; routing incoming electronic mail to the user's electronic mailbox (or the LAN's mail system if the receiver is on a server with mail); routing facsimiles to an output device; accepting and storing binary files including software, knowledge database indices, and application files; installing (or holding for approval) updates to existing software, as designated by the user. Although the great reduction in mass storage cost has resulted in hard disk drives with capacities greater than 1 gigabyte today and perhaps 10 gigabytes in a few years, the user agent software will incorporate a storage priority system, customizable by the user, to prevent overload of the user's storage device. The user agent will also employ storage recovery mechanisms.

E. BACKHAUL MECHANISM

Each DBCS receiver will have a backhaul mechanism to support the transmission of accounting and usage information back to the network's system administrator. Fixed site receivers will be able to output their information using a conventional modem connection

with a voice grade dial out line; via electronic media; via optical character recognition ("OCR") legible paper reports that can be mailed to Petitioners by the user; or through other means. Nomadic or portable receivers also could output their information using a wireless RF backlink, e.g., Cellular Telephony Data Packet Switching, Ardis®, RAM Mobile Data Service, or similar systems.

III. FUNCTIONAL DESCRIPTION OF OPERATIONAL FEATURES

A. SYSTEM AND DATA SECURITY

Data Integrity. Petitioners' architecture will be able to offer the delivery of highly reliable data using forward error correction over the spread spectrum technology outlined in Appendix A. For those vendors requiring even higher accuracy levels, additional forward error correction algorithms can be employed. In addition to the advantages of spread spectrum, Petitioners' architecture, which minimizes nodes through which a message passes, enhances the potential for transmission of a clean signal.

Receiver Authentication. The DBCS data stream will be sent in packets with encrypted message headers addressed to individual receivers. The level of encryption will be equal to or greater than that employed in DES key systems. Vendors will optionally be able to encrypt their entire messages.

The nature of spread spectrum makes it very difficult for a would be information pirate to intercept and capture a DBCS signal. Additionally, the proprietary nature of the receiver with its embedded chip design presents another hurdle to an unauthorized user. The

receiver is able to read and decrypt the header information. Receivers will be able to be "turned off" with a message sent through the data stream.

B. INFORMATION ACCESS/SUBSCRIPTION SYSTEM

DBCS will provide vendors with a rich array of options for providing access to information for current and potential users. Some examples include:

- Vendors can choose to provide their data on a one time or subscription basis.
- Vendors will be able to choose whether a user may access the vendor's information at an authorization level controlled by the receiver, at a higher level within DBCS, or by the vendor itself.
- Users will be able to set up a filter to screen out unwanted solicitations and data.
- Vendors may include a promotional piece on the information they have available to a browsable "newsline" available to all users or users who fit a specific profile.

C. ACCOUNTING SYSTEM

Accounting for the DBCS system involves two elements, rendering accurate records of end user access to information providers' data and tracking information providers' use of the network for billing purposes. In developing records of access, DBCS's accounting system will be fed by data received from the regional centers, which includes both subscriber list information and information transmitted over the backhaul links regarding specialized access billing. The collection centers also provide the data necessary to determine bulk data input from vendors and vendors' use of specialized billing or priority categories.

The DBCS architecture has been structured as flexibly as possible for information providers and end users. By relying on Oracle's extensive tools for managing information, however, this flexibility also will be manageable for all vendors, whether long term regular users or one time only users. On the information user's end, the same types of software resources are used to maximize the ease of use and the utility of the data to the computer user. Thus, the architecture itself is designed to maximize options and promote productive use of information. The DBCS Architecture is shown in Fig. 17.

APPENDIX C

MARKET DEMAND STATISTICS

I. MARKET OVERVIEW

The Petitioners have held extensive discussions with a number of potential information providers and data vendors over the last two years. These discussions have been instrumental in shaping the design of the product and assisting Petitioners in sizing the potential market for DBCS.

It is estimated that the market potential has two identifiable categories. First are situations where use of Petitioners' or other DBCS network would replace a current method of data distribution. The major line items of this category are:

- Data transmissions which currently take place over telephony lines where DBCS transmission would be lower in cost and/or faster.
- Cost of materials and distribution via magnetic medium, for example floppy disc software and CD-ROMs (including documentation).
- Printing and distribution of business and professional periodicals.
- Printing and distribution of maintenance documentation and other company to customer data.
- Printing and distribution of governmental information.

The cost of distribution of data in just the above mentioned categories is estimated to be in excess of \$33.5 Billion annually. If a DBCS network is not put in place, and conservatively

estimating the situations where distribution via DBCS would be appropriate,¹ data vendors will spend the following sums (in aggregate) distributing their data in the next five years:

REPLACEMENT MARKET (\$ x 1,000,000,000)

1993	1994	1995	1996	1997
\$3.57	\$3.75	\$3.94	\$4.16	\$4.39

DBCS would provide significant savings for these information providers. In fact, Petitioners believe that the savings in distribution, the greatly increased operating efficiency gained by the speed of DBCS delivery, and the ability to address users' terminals individually, will lead to the creation of new markets for information services. While it would be difficult to quantify this second category of potential opportunity with any accuracy, these new applications are the ones which will enable those businesses and individuals who are currently information disenfranchised.

The development of new applications, will of course take time and require changes in human behavior. Many emerging technology concepts have not been sustainable because they have not had an immediate application, and therefore revenue stream, on which to draw and with which to introduce users to the new concept. With its significant potential revenue base in immediately deployable applications,² Petitioners' venture will have the where-with-all to sustain itself, both from a financial and user acceptance standpoint.

¹ While DBCS transmission could functionally replace a higher percentage of current distribution costs, the Petitioners recognize that alternative methods do exist, although generally at higher cost or lower speed, and that for a variety of business reasons information providers will continue to utilize current methods. Moreover, the Petitioners believe that in the case of on-line transmission services, some applications will continue to require a two-way real time connection.

² Petitioners have held serious discussions with a number of potential customers and, in fact, have signed letters of intent with major vendors.

II. EXAMPLES OF POTENTIAL NEW APPLICATIONS

The following are examples of potential new distribution applications where a DBCS network would provide significant gains in productivity, efficiency or provide a needed public benefit.

A. APPLICATIONS IN THE SCHOOLS

Apple Computer estimates that there are 3-3.5 million personal computers deployed in America's K-12 public schools. However, all this equipment is not being leveraged for learning. Children love computers and can devour large varieties of programs but find themselves isolated on the island campuses. In an age when connectivity in PCs is spreading through businesses and enabling the sharing of thoughts, data, ideas, and software, few schools can afford the telephone lines to enable them to access the vast resources of information currently available on-line. In this age of cost cutting, acquisitions of textbooks and reference materials are some of the first things to go. Some textbooks in use today still have Lyndon Johnson as President.

Schools also need a variety of fixed cost services in the areas of administrative support, teacher education, and curriculum focus. DBCS could more efficiently, and cost effectively, deliver the majority of the estimated \$108 million dollars in software schools purchased last year. Additionally, DBCS could provide a more efficient marketing tool for software developers enabling them to reach the educational market with less promotional expense. Schools will also become an attractive 'aftermarket' for other information distributors.

B. A NEW APPLICATION FOR THE CENTER FOR DISEASE CONTROL

Currently, the Center for Disease Control ("CDC") updates its 3000 reporting entities weekly on disease statistics and treatment protocols via paper. DBCS could provide CDC with a more efficient distribution vehicle and make it easier to reach their traveling clinicians. Additionally, as their charter is broadening to provide information to a wider audience in the wake of the AIDS epidemic, DBCS could provide a low cost distribution system to hospitals and primary care physicians. Similar services are easy to imagine for the many branches of federal, state, and local government, and for military and civilian organizations.

C. DISTRIBUTION OF MAINTENANCE MANUALS

Each year, over 1,000 different manuals are printed and distributed on the maintenance of just the U.S. aircraft fleet. Over 1/2 million pages of updates are sent out and inserted into those manuals. The use of Petitioners' network and user agent software could increase productivity dramatically. Manuals, stored electronically, automatically have updated information inserted and out of date material deleted. The process takes hours from issuance of new material instead of the current weeks. Important new changes are highlighted. Safety is enhanced, costs are dramatically lowered and the possibility of error is greatly reduced. Similar systems could serve other industries with complex documentation needs, including military equipment, vehicles, farm and construction equipment, manufacturing, and computers.

D. LIBRARY COLLECTION ENHANCEMENT

In 1990 libraries spent over \$766 million on periodicals, microform, machine readable formats, and database fees. Yet the combined pressures of budget and storage space constraints are causing many to cut back in expenditures, particularly in these non-classic segments. Interlibrary loans, despite electronic networking, can often take weeks to fulfill a request and then the lending library must do without the document. DBCS, by decreasing distribution costs and lowering the overhead of inventorying material could ease some of these burdens.

This situation exists for a wide range of libraries from small public libraries, to large university research centers. In fact, the Association of Research Libraries reports that its 94 members bought 570,000 fewer books in 1989 than in 1985. This reflects in part a reaction to the 51 % increase in the price of professional and technical journals within the same period. The University of California Library at Berkeley reports that it has canceled \$400,000 worth of journal subscriptions. As the market for these publications contracts, they are forced to raise prices even faster to cover their overhead or go out of business.

The net result is both a threat to our overall educational level as a society and to our industrial competitiveness. DBCS offers a number of ways to improve the situation. First, current on-line database providers could offer their services less expensively by downloading their "search trees" and allowing users to search off-line. Second, DBCS provides a more cost effective distribution system for current information providers, including publishers of special interest journals. Third, by lowering the overhead of information providers, and

providing a more efficient marketing vehicle (direct to the potential user) providers can economically offer their product to a wider user base.

E. SOFTWARE DISTRIBUTION

The Software Publishers Association reported sales of \$5.7 billion of prepackaged software in 1991. Software, the programs that drive computers, is still primarily distributed via trucks, warehoused, and mailed, and essentially distributed outside of the age of electronics which it represents. Software publishers are developing new editions of their product on an ever more rapid schedule — offering users new features and potential increases in productivity. However, the overhead of marketing and distribution remains nearly as high for updates as it is for the initial product.

Users of on-line consumer services have embraced receipt of software on-line. A recent survey by the Interactive Services Association reports that over 75% of users regularly download software. Unfortunately, the size and complexity of this software is limited by the speed of transmission. This limitation restricts the use of color, graphics, and other multimedia resources. Additionally, both consumers and business currently lack the ability to have their software updates automatically provided to them.

A DBCS network can empower users with new opportunities and lower the cost to publishers. The Petitioners estimate that if publishers relied on DBCS for just one in five upgrades of currently published software, it would reduce \$106 million in costs.

III. Replacement of Current On-line Distribution Methods

The following examples are ones which currently utilize two-way communications systems. DBCS would offer providers in the following applications an alternative for delivering their product where the majority of the volume of their information is flowing in one direction and the providers are seeking to reach a number of users; *i.e.*, point-to-multipoint.

A. ELECTRONIC MAIL

The Electronic Mail Association ("EMA") estimates that as of the end of 1991 there were 8.9 million users of electronic mail sending 2.3 billion messages annually. EMA also estimates that the number of users will grow to 27 million users sending 14.3 billion messages in 1995. IDC has estimated the combined revenues of the public mail networks (which carry less than half of all message volume) to have exceeded \$435 million in 1991.

Petitioners conservatively estimate that over 1.1 billion of these messages could more economically be sent using a DBCS network. Indeed, any message sent to more than one recipient is more efficiently conveyed by a broadcast system. DBCS would be a very efficient vehicle for delivering mail to recipients who are located at a different location (both internal and external to a company) from the sender. It would also be very cost effective for delivering broadcast messages, messages with long distribution lists, and messages which contain a mix of electronic mail and facsimile mailboxes. It is anticipated that a DBCS network would utilize the existing and emerging X.400 and X.500 standards for message routing and directory formatting.

B. ONLINE NEWS AND SERVICES

Communications Trends, Inc. estimates that over \$11.8 billion dollars was spent on electronic and printed databases last year. A significant expense for these publishers is distribution of their product. For example, many of the news wire, financial, and currency trading services utilize two-way telecommunications schemes, including expensive leased line connections, to deliver their data. These schemes require the information providers to maintain a substantial overhead to support the individual virtual connections with each receiver. Yet, the real data is only being sent in one direction -- to the users. Even those information providers who are able to employ VSAT and FM sideband technology, and thereby solve the point-to-multipoint issue, must maintain alternative systems because many users are not technically able to receive VSAT or FM signals. One of the potential customers contacted by the petitioners indicated that he never thought that being so heavily enmeshed in the telecommunications business would be part of his business plan, but that telecommunications is an integral part of getting product to his customers.

Additionally, large mainframe based databases use an enormous amount of computer resources in the search process. With the dramatic reduction in the cost of personal computer based storage a user could perform this search much more efficiently off-line. However, until now, there has been no way of efficiently updating the "search tree." The DBCS scheme envisioned by the Petitioners would allow the information provider to update the search tree as required on the user's computer, thereby giving the user timely information and putting the database operator back in the business of providing data.

Other online service providers are limited by the speed of the deliver vehicles available to them, and they are reliant on users to dial into their services to get updates. With users on a DBCS network, providers will be able to flag important stories to their attention and economically provide the kind of data transmission throughput that will allow even average users, including small businesses, to receive information real time.

A DBCS network will also offer advantages to information providers who currently publish their databases on paper or electronic media. Today these providers must republish and re-distribute their work in order to keep it up to date. This represents significant overhead to the provider and makes for an often out of date document for the user. Using DBCS, database publishers will be able to efficiently and continuously update their material. They will also have an efficient marketing vehicle to their current and potential user base to inform them of new products and headlines.

If just one in five of the information providers who could viably use a DBCS network for product distribution did so, they would significantly lower an estimated \$829 million distribution expense. Additionally, by lowering the provider's overhead and therefore the ultimate cost to the user, the Petitioners strongly believe that information providers will be able to broaden their market and make their information accessible to businesses and consumers who are currently without efficient information resources.

IV. COMPETITIVE STRENGTHS OF DBCS

We believe that the current methods of broadcasting data -- FM sideband, VBI, VSAT, leased lines and paper each have limitations that DBCS overcomes. The constraints of these alternatives are summarized as follows:

FM sideband currently offers data rates of 19.2 kbit/s (orders of magnitude slower than DBCS), and has difficulty penetrating buildings, often requiring use of external antennas.

- VBI almost invariably requires an external antenna, provides data rates of 9.6 kbit/s per line, with few lines being available and no real potential for nationwide service.
- While the costs of VSATs have come down enormously, urban area installations range from \$1,000 to \$10,000, with new installations difficult or impossible in many urban areas due to line-of-sight considerations.
- Leased lines are point-to-point and expensive when used for distribution to multiple users.
- Papers limitations have been discussed, *supra*.

In comparison, DBCS is generally low cost and does not suffer from requiring external antennas, requiring site leases, limited capacity, or limited in-building coverage.

V. CONCLUSION

As shown, information providers' needs for DBCS services is immense. The DBCS network not only provides value by replacing a huge, multibillion dollar market for the wide area data transmission of bulk data that is currently being served inefficiently and expensively, the service also enables a rich variety of new services that are specifically

enabled by the speed and cost effectiveness of DBCS. And, unlike many new service proposals that must wait for consumer acceptance before becoming viable, DBCS can grow from a readily accessible user base replacing existing services into the market for new services comfortably and without great initial losses.

Omnipoint requests a Pioneers Preference for a license to operate PCS voice and data services based on its significant original engineering and networking work. Omnipoint's innovations have resulted in numerous firsts in the actual implementation of equipment and products which will significantly speed up the deployment of PCS in the complex U.S. regulatory environment. Our many technical innovations will be outlined below, but perhaps the most significant difference characterizing our request from that of others is that over the past five years we have actually designed, prototyped, field tested, and now productized for delivery to experimental license holders revolutionary spread spectrum wireless pocket phones and base

stations. These pocket phones can now operate in both the emerging technologies band (1850-2200 MHz) which will allow PCS deployment on a shared licensed basis, as well as in the existing spread spectrum bands (902-928 MHz and 2.4-2.4835 GHz) for unlicensed applications.

Omnipoint's system produces dramatically less interference to other users of the same frequencies and provides for an extremely fast track method of deploying PCS services. Omnipoint's system is significantly different from other spread spectrum system and is designed for shared operation with existing Operational Fixed Services (OFS). As important, the Omnipoint Spread Spectrum Microcell system has been designed and tested for use with both public and private networks independent of the specific network architecture. These include the Advanced Intelligent Network (AIN), cable TV systems, as well as PBXes, Centrex, and Key Systems. Omnipoint's handheld spread spectrum phones and microcells have been field trialed since 1990 in conjunction with many different potential infrastructure providers including Bell Atlantic, Pactel, Ameritech, Cox Communications, and many others. Omnipoint's equipment has been tested in over 40 cities and in virtually every type of building and operating environment.

In December 1990, Omnipoint conducted at Bell Atlantic Network Services' beta site the first wireless PCS test of the Automatic Location Tracking feature of AIN for routing outbound calls to mobile users. In addition, Bell Atlantic and Omnipoint

began initial Telepoint (i.e., inbound only) tests which were summarized in our first experimental license report.

After nearly 18 months of joint field testing, Bell Atlantic has contracted with Omnipoint for the purchase of several thousand units for PCS market trials using the unlicensed spread spectrum bands later this year. Pactel, Ameritech, and Cox, among others have also purchases Omnipoint's phones. In conjunction with Cox, Omnipoint's phones were used to make the first PCS call over a cable TV network, placed to Chairman Sikes in February of this year.

Omnipoint has also conducted its own tests within the Bell Atlantic territory and in every other region of the U.S. In particular, Omnipoint has done extensive field surveys in New Jersey. If awarded a Pioneers' Preference in the requested area of Northern New Jersey, Omnipoint would be able to have initial limited PCS services operational before the end of 1992.

Omnipoint and Bell Atlantic have signed a Letter of Intent under which Omnipoint will be able to purchase custom combinations of AIN features, microcell interconnection to the PSTN, and other PCS related network and operator services from Bell Atlantic. ⁽¹⁾

Omnipoint will be able to use any transport layer to access these AIN features, including cable TV networks if

1. These AIN services are similar to those being trialed in conjunction with the cellular operator trials in Pittsburgh, and are a superset of the ones originally tested by Omnipoint in December 1990 with Bell Atlantic.

Omnipoint chooses. Thus, PCS independent of a particular network topology can be deployed and showcased.

We feel that it is critical for the future success of PCS that independent service operators such as Omnipoint be able to have access to the enormous investment in infrastructures and networking intelligence incorporated into the Public Switched Telephone Network. Omnipoint's proposal will lead the way in demonstrating how this will be feasible.

If awarded a Pioneers Preference, we will offer our Common Air Interface (CAI) as an open standard. More importantly, we will work with the relevant industry groups to establish a standard even if it means changing our own architecture in major ways.

CORPORATE BACKGROUND

Omnipoint Corporation was incorporated in 1987 and specializes in developing spread spectrum communications systems for a variety of end user applications requiring wireless voice, data and video links. Omnipoint is a privately held company with financial backing from the investment banking firm of Allen & Company, which was the founding investor of MCI.

With over 300 person-years of experience in spread spectrum technology, Omnipoint has assembled one of the most knowledgeable teams of engineers and scientists in the industry. Accomplishments of Omnipoint personnel include:

- Development of the first producible spread spectrum system,

- Design of the Fleet Satellite Communications Network,
- Design of both hardware and software for the "next generation" National Security Agency encryption chips,
- Authoring the first textbook on spread spectrum theory and application.

In addition to voice products, Omnipoint also provides wireless data communications products to companies such as the world's largest supplier of communicating hand held terminals. Additionally, teamed with Texas Instruments, Omnipoint was chosen by the Chicago Board of Trade and the Chicago Mercantile Exchange to develop a prototype wireless communications system for their automated commodities trade reporting system. Omnipoint was selected after a competitive bidding process involving over one hundred vendors.

Omnipoint began designing the technology which became incorporated into the equipment described in this document in 1987. In August 1990, Omnipoint applied for an experimental license (awarded in December 1990) call sign KF2XEH, File Number 1629-EX-PL-90, to begin field testing of its spread spectrum equipment. Omnipoint selected the unlicensed spread spectrum bands (known as the ISM funds) for its experiments since at the time these were the only frequencies available for eventual legal deployment.

Omnipoints system uses a gallium arsenide integrated front and receiver which can operate from 800 MHz to 2.5 GHz. Omnipoint has performed extensive tests of its technology in the

900 MHz bands, and confirmed its operation at 2.4 GHz. These experiments are documented on its experimental reports.

On July 29, 1991, Omnipoint applied for an experimental license at 1.85-2.2 GHz. This license was not granted until March 12, 1992, call sign KK2XCV, File Number 2174-EX-PL-91, and therefore no formal experimental report is due. However, because we began development of our 1850-2200 MHz equipment under our contract with Ameritech for their experimental license, we were able to begin field testing of our equipment immediately upon the grant of our 1850-2200 MHz license. This work resulted in the first 1850-2200 MHz handheld spread spectrum phone.

Preliminary results indicate that the phones perform as well at 1850 MHz as at 900 MHz. Limited experimental results are included in our most recent experimental report and referenced herein.

CHALLENGES FACING PCS

Three major technical challenges dominate the issues facing the PCS industry's implementation of new mobile voice services:

- I. How to migrate PCS into the Emerging Technologies bands on a non-disruptive co-existence basis with the existing OFS users;
- II. How to provide spectrum for both licensed MSA services as well as unlicensed equipment purchases (for PBXes, residential phones, etc) and allow consumers to use the same handsets for both

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applications on an as needed basis without disruption to either the PCS operators or the OFS users; and

- III. How to provide for a Common Air Interface (CAI) that can operate with different network topologies (one way, two way, PSTN Central Office based networking, AIN, SST, distributed mobility management networking, cable TV networking, etc.)

Omnipoint has pioneered solutions to all three of these challenges and is working with the major industry standards committees to achieve the beginnings of consensus.

OMNIPPOINT'S PIONEERING SOLUTIONS

The following summarizes Omnipoint's major developments. These innovations are not just proposals, they are also embodied in operational pocket phones and microcells developed over the past five years and now being tested by several independent potential PCS service providers.

- I. Omnipoint's System Will Allow PCS to Migrate into the OFS Bands With the Least Disruption and Maximum Flexibility.
 - A. Omnipoint's Spread Spectrum System Allows For Exclusion Zones Around the OFS Towers That Are 10 to 100 Times Smaller Than Equal Powered Narrowband Systems.
 - B. Omnipoint's Spread Spectrum System Uses 10 MHz and Sub 10 MHz Frequency

Channelization with Frequency Agility to Match the Existing OFS Channelization Scheme and Minimize Interference.

- C. Omnipoint's Spread Spectrum System Uses Time Division Duplexing (TDD) and is Capable of Combining TDD with Frequency Division Duplexing, Thus Allowing Maximum Flexibility of Operation in the Contiguous Niches of Geographically Unused OFS Spectrum.
- D. All of the Omnipoint Handset and Base Station Channels Combined in a Cell Produce Less Interference Than One Traditional Narrowband FDMA Handset Channel.

II. Omnipoint's System Provides an Immediate as well as a Long Term Solution to the Problem of Finding Spectrum for Both Licensed and Unlicensed Operation of the Same Handsets.

- A. Omnipoint's Handsets Can Switch Between the Emerging Technologies Band (1850-2200 MHz) and the Existing Unlicensed Spread Spectrum Band (2400-2485 MHz).
- B. 80 MHz of Spectrum is Available Immediately in the Unlicensed 2.4 GHz Spread Spectrum Band for At Least an Interim Part 16 Allocation for PCS.

- C. Part 16 Type Operation is Not Feasible on a Coexistence Basis with the OFS Users. Part 16 Type Operation in the OFS Band Will Require a National Allocation and Band Clearing of the Same Frequencies in All Cities. A Minimum of 40 MHz is Needed for Unlicensed Equipment, Which Could Take Years to Reallocate From OFS, Especially Given Licensed PCS Priorities and the Requirement to Pay for Relocation.
- D. Omnipoint's Handsets and Base Station Can Operate Anywhere in this Spectrum or in Other Nearby Bands if Reallocation Occurs Later, Thus Providing a Long Term Migration Path for Unlicensed Applications.
- E. Omnipoint's Spread Spectrum System Can Operate in an N=3 Frequency Reuse Pattern, and Even N=1 (With Less Capacity). Omnipoint's System Can Maintain this Reuse in a Three Dimensional Frequency Space Such as an Office Building. Narrowband Systems Require an N=25 Reuse Pattern and In Some Cases up to N=50 for use in such Three Dimensional Environments.

III. Omnipoint's Base Station to Network Interface is being Designed to be Independent of Network Topology.

- A. Omnipoint's system uses signalling rates and interfaces compatible with ISDN, SS7, and IS-41 like network architectures.
- B. Omnipoint's Base Stations have been interconnected to the PSTN directly as well as over the Cable TV Network.
- C. Omnipoint's Base Stations have been used in wireless Centrex and wireless PBX and Key System tests for successful private premises operation.

OVERVIEW OF OMNIPPOINT'S PIONEERING INNOVATIONS

Before detailing specific technical accomplishments we would like to present our implementation achievements:

- First handheld, battery operated, direct sequence spread spectrum phones;
- First 1850-2200 MHz spread spectrum handheld phones;
- First time division duplexed spread spectrum phones (this was a major spread spectrum innovation and is critical for sharing in environments like the OFS 1850-2200 MHz bands, as will be detailed below);
- First frequency agile direct sequence spread spectrum phones;
- First spread spectrum PCS use with Centrex and PBXes;

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- First wireless spread spectrum microcell trialed with the Public Switched Telephone Network;
- First wireless PCS test of the Advanced Intelligent Network for automatically routing calls to a nomadic user;
- First PCS call over the CATV (cable TV) network;
- First palm sized modem capable of handling voice, data, or video;

Omnipoint's pioneering work falls into three broad

areas:

- RF and specifically spread spectrum product design, development, miniaturization, and deployment;
- System architecture design for coexistence with other users of the same frequencies;
- Design and development of a base station control interface that is compatible with the ISDN, SS7, and AIN features critical for PCS deployment regardless of network topology;

In short, Omnipoint is developing a series of PCS products which can allow multiple operators to provide wireless services in the immediate future by independently interconnecting to existing infrastructures. PCS can thus be offered by multiple providers without each operator being required to replicate the enormous investment in infrastructure and services already in place (or about to be offered) by the PSTN and cable TV operators.

DISCUSSION OF TECHNICAL INNOVATIONS

I. Why Omnipoint's System Minimizes Disruption to OFS

- A. All of Omnipoint's Handset and Base Station Channels Combined in a Cell Produce Less Interference Than One Traditional Narrowband FDMA Handset Channel.

As an example, if we assume worst case free space propagation to an OFS tower from all handsets and channels, a fully loaded Omnipoint microcell (at 100 mW) can operate within 5 miles of the OFS tower (outside its beampath) before raising its noise threshold by 1 db. Assuming Hata Medium City suburban propagation, the loaded cell can operate within 2.3 miles, and assuming Hata Large City Urban propagation on every channel the entire Omnipoint cell can operate within 0.39 miles.

In contrast, a single 100 KHz narrowband handset obtaining line of sight free space propagation (for example, from a balcony) under the same assumptions (i.e., 100 mW and outside the beampath) would have to be up to 35 miles away. For the Hata Medium City Suburban assumption the single handset would have to be up to 7.39 miles away, and 1.24 miles under the Urban loss assumption.

Given any propagation loss assumption, Omnipoint's system fully loaded can operate significantly closer to the OFS users than a single narrowband handset. The ramifications of this are dramatic for determining Exclusion Zones for sharing with OFS users as demonstrated by Figures 4 and 5.

In determining Exclusion Zones, Omnipoint varies many parameters such as antennae type, height, cell size, power, and propagation loss assumptions. But as a certainty check on potential interference to OFS, Omnipoint also always uses Free Space or Open Area Loss assumptions to determine the worst case. Others (including, but not limited to Motorola and Telesis Technology Labs) also do this. But some studies, most notably the original American Personal Communications report identifying at least 50 MHz of available spectrum in the top 11 MSAs, used the Hata Urban Model to determine exclusion zones. Differences in this one assumption account for most of the differences in exclusion zone estimates calculated in the many exclusion zone studies done to date.

It is extremely important to recall the ramifications of using different propagation assumptions. There are six Hata propagation models. Using Hata Large City Urban loss assumptions results in an exclusion zone that is roughly 2000 times smaller than an exclusion zone using Hata Open Area loss assumptions.

There will be many instances when a single handset can obtain line of sight Open Area propagation to a microwave tower -- from a balcony, a bridge, a mountain, a roof top party on the 4th of July, etc. In performing our own field measurements as part of our experimental licenses, we have found Hata Open type results in the real world are easily demonstrated.

However, neither the Hata models nor the TSB 10-E were developed to guide engineers in coordinating mobile transmitters

with fixed microwave towers. Hata models, in fact, were never meant for designing systems so that they would not interfere. They were developed to assist in designing cell sites to achieve coverage. TSB 10-E was not originally specified for short (eg under 17 miles) urban transmissions. Raising the noise level 1 db on many OFS systems would have no measurable impact since many of them have 10 to 20 db of "extra fade margin". Omnipoint believes the PCS and OFS industries need to develop new models specifically tailored for solving this particular coexistence problem.

B. Omnipoint's Spread Spectrum System Uses 10 MHz and Sub 10 MHz Frequency Channelization with Dynamic Channel Frequency Agility, to Avoid Existing OFS Users.

By employing 10 MHz and Sub 10 MHz frequency channelization, Omnipoint's system allows for OFS frequency avoidance on a cell sector by cell sector basis. While this can be employed by narrowband techniques, the spreading significantly reduces interference to analog OFS versus narrowband PCS Systems. More than 83% of all OFS systems are analog. Analog OFS systems essentially use a large number of narrowband frequencies within their 10 MHz and are thus much more susceptible to narrowband interferers than to a spread spectrum transmitter. This is discussed in detail in Attachment B. In summary, however, a 100 KHz signal produces 100 times the potential interference to an analog OFS user as a 10 MHz signal at the same power level.

A further advantage of the 10 MHz and sub 10 MHz channelization is that it provides an easy migration path into the band if OFS users can be relocated to other frequencies.

- C. Omnipoint's Spread Spectrum System Has Successfully Implemented Time Division Duplexing TDD and the combination of TDD and Frequency Division Duplexing, Thereby Greatly Increasing the Flexibility For Finding Shareable Spectrum on a Cell by Cell Basis and Providing For Multiple PCS Operators.
-

All exclusion zone studies show that even when 50-60 MHz of shareable spectrum is available in an MSA, the shareable spectrum appears geographically as a pseudo-random pattern of specific frequency channels available on a cell by cell basis.

In many cells it is impossible to find PCS spectrum available in appropriate non-contiguous "pairs" to allow frequency duplexing. Moreover, many existing OFS users do not adhere to the 80 MHz paired allocations. This compounds the problem and makes even buyout schemes less useful for Frequency Duplexed PCS systems, since there is no way to guarantee normal pairing. Because Public Safety and Local Government OFS users are permanently grandfathered, at least 22% of the OFS paths (and possibly more) may be permanent. This is likely to make exclusion zone methods of sharing with the OFS users a permanent feature of PCS.

Further, even in cells where Frequency Duplexed "Pairs" can be found, it is often impossible to coordinate them with adjacent PCS cells or other PCS operators.

- D. All of the Omnipoint Handset and Base Station Channels Combined in a Cell Produce Less Interference Than One Traditional Narrowband FDMA Handset Channel.

Perhaps most uniquely, Omnipoint's microcell uses a proprietary technique to manage communications to the handsets such that the total interference generated by a fully loaded cell with all handsets operating in full duplex creates no more interference than one continuous signal. This extremely unique feature means that an entire city wide grid of Omnipoint PCS cells can be modeled for coordinating spectrum usage with the OFS users by modeling the equivalent of just one continuous user in each PCS cell. This dramatically changes the exclusion zone profile of a city and makes cell site planning infinitely simpler.

Omnipoint has contracted with a major independent consulting firm to model the impact of Omnipoint's system parameters on their exclusion zone analysis for the OFS band. In addition, under our experimental license, we have initiated design of a test plan in conjunction with existing OFS users in order to trial the system in real world, shared, operation.

II. Omnipoint's System Provides an Immediate as well as a Long Term Solution to the Problem of Finding Spectrum for Both Licensed and Unlicensed Operation of the Same Handsets

As discussed above, Omnipoint provides an immediate solution to the problem of providing spectrum for unlicensed operation in both one short term and long term. By immediately using the existing unlicensed spread spectrum bands for unlicensed applications, private premises PCS can be implemented at least on an interim basis or a Part 16 basis without interfering with the OFS users or the licensed PCS service operators.

Private premises, unlicensed PCS is critical to the success of any new PCS licensed service. Omnipoint has conducted extensive market research surveys (including extensive interviews with 185 of the Fortune 1000 telecom purchasing managers). No company will pay air time charges to communicate wirelessly within their own premises. Companies and consumers want to own their own equipment. Yet they want the choice of potentially using the same handsets when they are in public areas.

Omnipoint has submitted technical papers to several committees demonstrating why unlicensed equipment can not coexist on a non interfering basis with spectrum shared with OFS users. This analysis was presented to the Technical and Engineering Committee of Telocator's PCS Division, which later voted 24 companies to 1 supporting the conclusion that Part 16 unlicensed equipment was unfeasible for sharing in the OFS bands. If Part 16 is to be achieved in those bands there must be a national

allocation for it and band clearing. The Technical and Engineering Committee also concluded that licensed PCS could not reliably coexist unlicensed Part 16 equipment.

Omnipoint's handsets can operate in both the Emerging Technologies band as well as the 2.4 GHz unlicensed band and can be user selectable. Omnipoint strongly recommends that a Part 16 ruling be undertaken for unlicensed PCS in the 2.4 GHz band. As documented by the NTIA studies and those of others, the 2.4 GHz band is the least utilized portion of the spectrum which they studied. Omnipoint's own studies performed under its first experimental license also show that the band appears to be unused currently for any communications activity.

Although the band provides for unlicensed Part 15 operation today, the rules allow tremendously disparate applications, modulation schemes, and power levels to be used. For PCS to be viable long term in this band a spectrum sharing etiquette must be adopted. Before many different unlicensed products are deployed in the band, the FCC and industry have a unique opportunity to implement such a sharing etiquette before it becomes impractical.

III. Omnipoint's System Can Interface With Different Network Architectures.

As noted above, Omnipoint has worked with Local Exchange Companies, Cable TV companies, cellular providers, and providers of private systems to design a network interface which

can allow Omnipoint's over the air protocol to operate independent of the network topology.

Omnipoint and Bell Atlantic Network Services have signed a Letter of Intent for the potential provision of various Advanced Intelligent Network services to Omnipoint should it be awarded a license within the Bell Atlantic territory. These AIN services are critical to the success of PCS as they will provide Automatic Location Tracking and "Follow Me Anywhere" profiles of a users preference for specific personalized service features, preferred long distance providers, caller screening criteria, etc. Much of what will make Personal Communications Services "personal" is embodied in such AIN features.

Omnipoint will be able to access these features regardless of the transport layer topology, including backhaul via cable TV or other networks. Attachment C outlines this AIN network approach.

WHY OMNIPPOINT'S SPREAD SPECTRUM SYSTEM IS UNIQUE

Omnipoint's system is unlike any of the other proposed spread spectrum solutions. It differs both in its architecture as well as in the specific techniques employed for synchronizing to and demodulating the signal. The following outlines the major design differences and their implications.

Spread Bandwidth and Channelization. Millicom/PCNA/SCS Mobilecom originally proposed a 48 Mhz Frequency Division Duplexed system, thus occupying 96 MHz of the 140 MHz POFS band. They named their system Broadband CDMA or B-CDMA (presumably to distinguish it from Qualcomm's spread spectrum system which seems to have taken on the name Narrowband CDMA by default). The near 100 MHz spreading was advocated as a sharing solution with the POFS. B-CDMA underwent extensive initial tests on its ability to coexist with the POFS, but was the subject of almost universal attack as a sharing technique in the POFS bands, and has the limitation of supporting only one independent operator in the band. It has not yet undergone more than a single cell test and presumably would have to incorporate sophisticated adjustable power controls similar to Qualcomm's approach.

Qualcomm's system uses 1.25 MHz channels plus guardbands and is also frequency duplexed (thus using 2.5 MHz). It was not designed as a sharing technique, nor designed for coexistence in the 1850-2200 Mhz band. Rather, it was designed for operation within the cellular band, as a capacity enhancing technique relative to FDMA and TDMA approaches. The system

incorporates an extremely sophisticated adjustable power control system and requires operator controlled cell sites and high speed switching to manage the continuous soft handoff. It uses a variable rate vocoder with a maximum sampling rate of 8 kbps. Because of its 2.5 MHz duplexed bandwidth, it will be tested in the 1850-2200 MHz band on frequencies which attempt to avoid the OFS users.

Associated PCN proposed 5 MHz Frequency Duplexed channels although it is unclear whether they have developed any equipment or microcells to this spec beyond simplex test links.

Omnipoint uses 10 MHz and sub 10MHz Time Division Duplexed and can combine it with Frequency Division Duplexed channelization for the reasons discussed above. Coupled with Dynamic Channel Allocation this minimizes interference to the analog OFS users and matches the existing channelization scheme.

Duplexing Technique Omnipoint pioneered Time Division Duplexed (TDD) and Time Division combined with Frequency Division Duplexed (TDD/FDD) direct sequence spread spectrum. The spread spectrum solutions proposed by Millicom/PCNA/SCS Mobilcom, Qualcomm, and Associated PCN all proposed frequency duplexed systems. Direct sequence systems traditionally have required frequency duplexing since they could not synchronize fast enough to allow the constant turning off and on of a time division duplexed signal. In fact, Southwestern Bell in their IMASS proposal originally thought that because they concluded that TDD would be required for OFS sharing, this eliminated direct

sequence spread spectrum as a contender. In subsequent meetings with Southwestern Bell we demonstrated our TDD solution to them.

Operational TDD direct sequence is one of Omnipoint's original major accomplishments. Although other companies are now proposing it and prototyping it, Omnipoint had it operational in our laboratory screen rooms even before the famous July 11, 1989 FCC hearing on new wireless phone technologies which launched the rush toward PCS. TDD coupled with FDD is another Omnipoint first, and provides the ultimate flexibility for frequency coordination.

Omnipoint's extensive testing of the performance of TDD spread spectrum voice are well documented in its two experimental license reports.

As discussed above, all frequency duplexed systems will find it extremely difficult to find usable spectrum in the current POFS band in many cells due to the nature of POFS usage and the proposed grandfathering. Direct sequence spread spectrum frequency duplexed systems, even if narrowband, will find it even more difficult if they require an N=1 reuse pattern. Without an N=1 reuse pattern, many spread spectrum systems either cannot work at all given their network architecture or lose much of their capacity claims.

Cumulative PCS Cell Interference. All of the other spread spectrum systems generate interference in at least two OFS frequencies since they employ Frequency Division Duplexing. Moreover, each additional user at least linearly adds to the

interference in the two duplexed channels. Thus, for example, 32 users in a cell each at 100mW generates at least 32 times the interference as one such user. Millicom/PCNA/SCS Mobilecom system spreads across 100Mhz and will therefore create interference to at least ten 10Mhz and ten 5 MHz OFS channels. In their system all cells produce some interference to all of these OFS users. However, they are claiming extremely low transmit powers (less than 100 micro Watt) and plan to use adjustable notch filters.

Omnipoint's system never allows a cell to generate more interference than the equivalent of one continuous transmitter, regardless of the number of users on in the cell. At 10 MHz and Time Division Duplexing, the system need only avoid one OFS frequency in each PCS cell, and that OFS user needs to be at farthest only 5 miles away, and in a dense urban area less than 1 mile away (but always the PCS frequency is outside the beampath).

Frequency Reuse Millicom/PCNA/SCS Mobilcom and Qualcomm both currently require an N=1 reuse pattern. Associated PCN proposes a frequency hopped system without specifying a reuse pattern.

Omnipoint's system can use any reuse pattern including N=1 (although N=1 would limit capacity in most circumstances relative to the preferred N=3 reuse pattern, or require synchronization). A major advantage of Omnipoint's system is that base stations can be independently owned and operated since

they can also use dynamic channel allocation and operate unsynchronized.

Provision for In-Building PCS. Millicom/PCNA/SCS

Mobilecom would have no alternative but to provide in-building PCS in the same frequency as a licensed PCS operator since there is no other spectrum available due to their 100Mhz spreading. Thus, virtually by definition they will be unable to offer unlicensed equipment since all equipment must be coordinated with the licensed PCS operations.

Qualcomm's system is also explicitly designed to only provide in-building PCS as an extension of the wide area PCS operator's service. They propose a complex array of antennas for combining signals and differentiating users.

Omnipoint's system in contrast provides for an extremely simple and completely independent operation of licensed PCS and unlicensed equipment, without the need to coordinate spectrum, but accessible by the same handset on as demanded basis. As detailed above, the handsets can span completely separate frequency bands.

FOOTNOTE: We understand that PCNA has shifted away from SCS Mobilecom recently and is advocating a 40 MHz Time Division Duplexed System. We did not have enough details to make a comparison at this writing but the most obvious difference is in the spreading bandwidth. At 40 Mhz they will find it difficult to identify much unused spectrum for sharing with existing OFS as Omnipoint's system.

ADVANTAGES OF OMNIPPOINT'S SPREAD SPECTRUM OVER NARROWBAND SYSTEMS

The two most widely proposed narrowband systems for various PCS services are CT2 and the GSM/DCS-1800 systems. CT2 uses 100 KHz channels and DCS-1800 use 200 KHz channels.

Narrowband Causes Greater Interference to OFS

As shown in Attachment D, whether 100 KHz or 200 KHz, narrowband systems cause significantly greater interference to analog OFS towers. As detailed in Attachment D, the analog OFS modulation scheme consists of essentially many narrowband FM signals. Thus a single narrowband PCS user can interfere much easier than a 10 MHz or 5MHz wide PCS user.

The consequence of this is that narrowband systems require much greater exclusion zones. In the case of free space loss (which can be obtained by line of site conditions from or to a roof top or mountain, for example) a narrowband exclusion zone can be up to 100 times the size of Omnipoint's exclusion zone outside the beampath. Even using Hata Suburban Loss models, the narrowband exclusion zone for a single handset is up to 15 times the area of a fully loaded Omnipoint cell.

NARROWBAND SYSTEMS REQUIRE GREATER REUSE SEPARATIONS

Attachment D details analytically why non spread spectrum systems must employ significantly higher reuse factors, thereby lowering real world spectrum efficiency. Omnipoint's system is designed to operate with an N=3 reuse (as opposed to N=7 or N=12 for narrowband systems, depending on cell

sectorization). Further, with lower capacity or synchronized base stations, Omnipoint's system can operate in an $N=1$ reuse environment. The latter ability will allow the Omnipoint PCS system to work in cells which can avoid OFS exclusion zones but which narrowband systems can not utilize due to the fact that only the same frequencies are available in contiguous cells.

NARROWBAND SYSTEMS REQUIRE VERY HIGH REUSE FACTORS FOR IN-BUILDING MULTISTORY SYSTEMS

Most importantly, Omnipoint's system has been designed to operate in buildings with multiple stories. As Attachment D graphically demonstrates, narrowband systems can require $N=25$ up to $N=50$ effective reuse factors. This can be mitigated by using dynamic channel allocation, but Omnipoint's system can also use dynamic channel allocation.

Our experimental report exhaustively documents in building, multistory propagation characteristics. Worse than free space loss (i.e., less than $R=2$) frequently prevail as well as greater than $R=4$. Further, the frequency selective multipath fades are dramatic. Omnipoint's spread spectrum system has been designed to compensate for these severe conditions, a traditional narrowband systems will have more difficulty with indoor environments.

Tests of CT2 systems in-building in Canada, and documented with the DOC (there are several but the most explanatory is that reported by PhoneSpot) show that no more than four CT2 handsets could operate simultaneously within a room

although there were 40 100 KHz channels to choose from. Even when separated by several floors, the maximum number only rose to approximately 15 users, and there was significant interference reported. Our experimental results show extremely high quality voice coverage, with multiple simultaneous users on multiple floors.

CONCLUSION

Omnipoint has developed and field tested a unique spread spectrum PCS system capable of solving the three main hurdles necessary to deploy PCS in the U.S.:

An innovative spectrum sharing RF system which will allow a phased in approach to coexist with the incumbent OFS users;

A single handset using a sub-10 MHz, dynamic channel, frequency agile architecture and capable of operation over two separate 80 MHz bands -- one in the emerging technologies band and the other in the existing unlicensed spread spectrum band. This will allow immediate deployment of both licensed and unlicensed PCS.

A flexible network interface for deployment with various architectures using standard signalling protocols such as those employed in the AIN and the cellular industry's IS-41 spec across a variety of network topologies.

ATTACHMENT B
Abstract

Emerging technologies such as PCS will need to coexist with incumbent point to point microwave services on a unilaterally noninterfering basis. New systems must not disturb existing services. In this report we examine the effects of PCS interference on existing systems. In particular, we show that conventional analog multichannel voice systems¹ are much more sensitive to narrowband interference for a given power level. Omnipoint's 10 MHz spread spectrum signal, because of its noiselike nature and wide bandwidth, causes 1/100 (20 dB) less interference than a comparable power 100 kHz system would cause. As a consequence, our systems can operate in locations 10 times closer to the microwave tower without undue interference.

We further argue that the use of Hata propagation models may be unrealistic for establishing exclusive zones in the context of mobile users since a single handset can potentially obtain a free space propagation path to the microwave tower and jam it (often referred to as a "rogue" handset). In our opinion, several reports submitted to the FCC paint overly optimistic results on sharing by using Hata Urban models to derive exclusion ranges. In particular, American Personal Communication's report² claims out of beam width exclusion radii of 4 miles based on this model. Using the same parameters and a free space propagation model, theoretical exclusion ranges grow to 257 miles. Obviously, when earth curvature is accounted for, signals will

1. Roughly 85% of the deployed systems.

2. APC's July 30, 1991 report.

not propagate over these ranges but we do argue that the PCS industry needs to establish a standard set of realistic criteria for estimating exclusion radii.

Our final argument is that the protection afforded by TSB10-E is excessive in the context of many microwave operations. TSB10-E, the governing standard for interference with private radio services, was originally developed for long haul, multihop (e.g. 3000 miles) microwave services with large tower separations. Most MSA links in the 1850-1990 MHz band are short (i.e. less than 17 miles) and operate with extremely high fade margins. One study by COMSEARCH³ found that the average fade margin for OFS links in the Houston area is 54.4 dB corresponding to a 9 second outage time per year. Many of the links had expected outage times of less than one second per year. Relaxing TSB10-E standards on a case by case basis appears highly desirable.

Introduction

Most of the 1850 MHz to 2200 MHz spectrum is currently allocated to industrial and public service OFS⁴ and fixed site microwave services on a licensed basis. Table 1⁵ summarizes

3. COMSEARCH, "Exploring Alternate Bands For 1.9 GHz Systems", 20 January, 1992.

4. Operational Fixed microwave Service.

5. From: "Creating New Technology bands for Emerging Telecommunications Technology", Office of Engineering and Technology, Federal Communications Commission, Washington D.C. 20554, OET/TS 91-1, December 1991.

typical uses in these bands. Studies by the U.S. Department of Commerce⁶ indicate comparatively low activity on the existing links. WARC92 international treaty agreements⁷ signed in March suggest allocating substantial amounts of spectrum⁸ to FPLMTS⁹ in these bands, worldwide. These factors, combined with good propagation characteristics make this band a strong candidate for eventual reallocation to PCS services as was recommended by the FCC's NPRM regarding the Emerging Technologies Band.

Initially; PCS services will have to share such an allocation on a unilateral noninterfering basis. It is our position that this must be done on a licensed basis. The critical nature of many OFS services, particularly in controlling the nation's electric power grid makes the ramifications of inadvertent OFS disruption extremely serious. Unless the bands are cleared, unlicensed part 16 operation¹⁰ is likely to disrupt licensed OFS users. New PCS services should not interfere with existing microwave services. We presented our analysis to the Technical and Engineering Committee of Telecater's PCS Division and the position adopted by a vote of 24 companies to 1 also concluded that unlicensed Part 16 operation on a shared basis was unfeasible.

6. "Spectrum Usage Measurement in Potential PCS Frequency Bands", NTIA Report 91-279, September 1991.

7. "WARC Final Press Release", 3 March 1992.

8. Greater than 200 MHz.

9. Future Public Land Mobile Telecommunications Systems.

10. Similar to part 15 except with a spectrum etiquette added to reduce mutual interference between type certified equipments.

Studies by Telesis Technology Laboratory¹¹, Motorola¹², Southwestern Bell, Impulse TeleCom and several others indicate instances of heavy spectrum utilization over small geographic regions in many MSAs. In these areas, careful frequency/base station site selection studies will be needed to ensure compatibility with existing microwave licensees. This is possible only in the context of a formal licensing process. This is not to imply that we do not favor part 16 style operations; particularly for indoor operations. We believe there is sufficient spectrum available in the ISM bands¹³ currently operating under part 15 rules. Incorporating the spectrum etiquette rules of part 16 into these bands would help ensure equitable band sharing and at the same time avoid dislodging licensed users in the 1850-2200 MHz bands.

Coexistence with POFS in the 1.9 GHz Band

The 1850 to 1990 MHz (1.9 GHz) band is currently dedicated to Private Operational Fixed Services (POFS). These are high capacity point to point microwave voice and data links between fixed stations. A typical link consist of two stations, each employing a high gain microwave dish antenna mounted on a tower. The antenna point towards each other to provide upwards of 60 dB

11. "Progress Report on Experimental Licenses: KF2XFD (File Number 1658-EX-PL-90) etc." Submitted to FCC November 20, 1991.

12. "Comments on General Docket No. 90-314", Submitted to FCC July 24, 1991.

13. 902-928 MHz and 2400-2483 MHz.

of additional link gain. The upper section of Table 1 indicates some representative users of this band while Table 2 indicates specific licensees in the Boston area.

EIA/TIA Telecommunications Systems Bulletin TSB10-E "Interference Criteria for Microwave Systems in the Private Radio Services", dated November 1990 is the governing standard for interference with OFS systems.

OFS systems fall into two broad categories, digital data and analog voice systems. Studies by COMSEARCH and others suggest that most OFS links in the 1.9 GHz band are analog voice type systems using older technology radio equipment. As an example, one study¹⁴ found that over 85% of the OFS links in Houston¹⁵ used analog transmission formats. Impulse TeleCom estimates the national distributed of analog systems at 83% of the total.

Analog systems use a single, narrowband FM¹⁶ transmission carrier modulated by a Frequency Division Multiplex (FDM) baseband signal. To generate the baseband signal, 3.1kHz bandwidth voice channels are Single Side Band Suppressed Carrier (SSB-SC) modulated up to different center frequencies spaced 4 kHz apart. Figs. 18-19 and 18-16 documents the formation of a 600 channel (10 supergroup) SSB-SC FDM baseband signal. Once the FDM baseband signal is formed, it can be carried over a single FM carrier as shown in Fig. 18-2.

14. COMSEARCH, "Exploring Alternate Bands For 1.9 GHz Systems", 20 January, 1992.

15. Second only to LA in number of OFS links.

16. Typical modulation indexes are less than 1.

Table 3, taken from TSB10-E, documents typical modulation parameters for analog transmission formats. Of particular importance for interference calculations, the modulation index is small; the baseband signal's channelized spectrum structure is preserved in the FM carrier signal. In terms of spectral usage, the composite SSB-SC FDM FM signal is really an array of narrowband voice channels spaced 4 kHz apart. This is significant because a sufficiently narrow interfering signal can concentrate essentially all of it's energy in a single voice channel without affecting the others¹⁷. As a consequence, narrowband interfering sources will be more damaging for a given power level than wideband sources.

TSB10-E, , the governing standard for OFS interference defines maximum allowable interference criteria for OFS systems. In particular, it requires no more than 1 dB of threshold degradation for analog systems. When transmitting in the direction of an OFS receiver, if we are to use the same frequency, an exclusion zone must be established. The required exclusion range is a function of transmit ERP, bandwidth, allowable OFS receiver threshold elevation and propagation characteristics. *Figs. 18-4a and 18-4b* plots required exclusion zones as a function of transmit ERP when transmitting in band but outside of the OFS antenna mainbeam. A free space, line of sight propagation model has been used to upper bound required exclusion range. Our 10 MHz bandwidth system,

17. Ignoring intermod effects.

18. Appendix A documents the specific methodology used in computing these curves.

operating at its nominal 100 mW transmit ERP can use the same frequency as an OFS receiver as long as it is more than 5 miles away and not in the transmission path. Corresponding 200 kHz and 100 kHz narrowband systems must be 35 to 55 miles away if free space propagation prevails.

If we assume a 4/3 smooth earth model, horizon limited line of sight range is 27 miles for a microwave tower height of 180' and an interference transmitter height of 30'. In most situations this range specifies the maximum propagation distance but it should be noted that ducting phenomena associated with atmospheric inversions can significantly extend propagation distances. When the refractivity gradient dn/dh exceeds -157 N units/km, rays leaving an antenna can be trapped in a duct and propagate overlong ranges with low losses. This is a particular concern in over water links in coastal regions where high humidity prevails. Exclusion zones extending beyond the 4/3 earth horizon may be needed for operation in the mainbeam of the OFS receive antenna when using the same frequency.

Comments on the use of Hata Propagation Models

During the late 1960's Y. Okumura et al. performed extensive propagation loss measurements in the 100-1500 MHz band for geometries typical of land mobile communications systems (eg. cellular). Hata. ¹⁹later compiled these results into a set of

19. Hata, "Empirical Formula for Propagation Loss in Land Mobile Radio Services", IEEE Transactions on Vehicular Technology, August 1980.

easily applied formulas used to describe average propagation path losses. The Hata model correctly predicts average propagation loss but it does not account for the variability of propagation conditions.

Figs. 18-4c and 18-4d show measured OFS tower to mobile signal strengths for two different towers. Predictions based on various Hata models and free space models are also included. On average, there is good agreement with the Hata model, but note the significant deviations. At one point on *Fig. 18-4c* measured signal strength is a factor of 1000 (30 dB) times stronger than predicted by the Hata model. In fact, signal strength is within 10 dB of free space predictions. A single mobile unit at this location is equivalent to 1000 mobiles at "average" locations.

Thus, the use of Hata propagation models may be unrealistic in the context of determining exclusion zones based on mobile sources of interference since a single "rogue" handset can potentially obtain a free space propagation path to the microwave tower and jam it. Given a large set of users, the chances of at least a few users being in "exceptional" low (i.e. near free space) propagation loss locations is significant. Exceptional conditions not modeled in the Hata equations include: operation in tall buildings, standing on a balcony, mountain top microwave towers, etc. Under these conditions, near free space propagation is likely to prevail into the OFS receiver.

20. Taken from "Comments on General Docket No. 90-314", Submitted to FCC by Motorola on July 24, 1991.

In our opinion, several reports submitted to the FCC obtain unrealistically optimistic results on sharing by using Hata Urban models to derive exclusion ranges. In particular, APC's report²¹ claims out of beampath exclusion radii of 4 miles based on this model. Using the same parameters and a free space propagation model, theoretical exclusion range grows to 257 miles.

Figs. 18-5 and 18-6 depict exclusion zones required for 100 kHz and 10 MHz systems respectively when using Hata Urban and Suburban models. Results from a free space model are also included. In both cases we note that the Hata Urban model predicts exclusion radii that are significantly smaller than the free space model.

Omnipoint takes the position that responsible coexistence with OFS systems requires consideration of the "rogue" handset problem. We explicitly recognize the potential for near free space propagation conditions. To this end, we have designed our system to minimize interference coupling into OFS receivers by using direct sequence spread spectrum transmission formats.

Comments on OFS Fade Margins

Our final argument is that the protection afforded by TSB10-E is excessive in the context of many OFS operations. TSB10-E, the governing standard for interference with private radio services, was originally developed for long haul, multihop analog microwave services with large tower separations and cumulative

21. _____.

interference effects. Most MSA links in the 1850-1990 MHz band are short range (i.e. less than 17 miles), single hop systems with extremely high fade margins. A study by COMSEARCH²² found that the average fade margin for OFS links in the Houston area is 54.4 dB.

Referring to *fig. 18-7*, this corresponds to a link outage time of 9 seconds per year for a 20 mile link or a link reliability of 99.99997%. End to end equipment must have a mean time between failure of 2.4 million years to provide this grade of service. Under these circumstances, we believe the OFS link is much more likely to fail because of equipment failures. Also, many of the links examined by COMSEARCH had expected outage times of less than one second per year.

Figs. 18-8 and 18-9 show how exclusion zones become smaller as allowable degradation of OFS threshold is increased beyond the TSB10-E limit of 1 dB, again assuming free space propagation. A 6 dB threshold elevation has the same effect as lowering fade margin by 6 dB. With a 48.4 dB margin, outage times are still only 25 seconds per year for a 20 mile link; much better than equipment reliability figures will allow for. Relaxing TSB10-E standards on a case by case basis appears highly desirable.

22. COMSEARCH, "Exploring Alternate Bands For 1.9 GHz Systems", 20 January, 1992.

Appendix A: Interference Analysis Methodology

During the late 1960's Y. Okumura et al. ¹ performed extensive propagation loss measurements in the 100-1500 MHz band for geometries typical of land mobile communications systems (eg. cellular). Hata ² later compiled these results into a set of easily applied formulas applicable under the following conditions:

- Frequency: 100 – 1500 MHz
- Distance: 1 – 20 km
- Base Station Antenna Height: 30 – 200 meters
- Mobile Station Antenna Height: 1 – 10 meters

In this report, the Hata equations are used to estimate propagation losses between PCS and microwave towers in the 1850 to 1990 MHz bands under the common assumption that propagation at these frequencies is very similar to propagation at 1500 MHz. It is important to recognize that Hata predictions are only an indicator of propagation parameters; actual propagation can differ significantly depending on the specifics of the propagation path.

With these caveats, table 1.1a shows sample spreadsheet results for computing propagation characteristics using the Hata equations. Predictions based on free space, line of sight propagation are also included to form an upper bound estimate.

1. Y. Okumura et al. "Field Strength and its variability in UHF and VHF land-mobile radio services", Rev. Elec. Commun. Lab. vol. 16, 1968. Reprinted in "Land-Mobile Communications Engineering", IEEE Press, 1984

2. M. Hata, "Empirical Formulae for Propagation Loss in Land Mobile Radio Services", IEEE Transactions on Vehicular Technology, August 1980.

Table 1.1a: PCS to Microwave Pathloss

Frequency (150 -> 1500) (MHz) : 1850
 Base Station Height (30 -> 200) (met) : 54.9 (180 feet)
 Mobile Station Height (1 -> 10) (met) : 1.8 (6 feet)

Propagation Loss L_p (dB) = $A - B \cdot \log(R)$ where R is in km

	Small/Medium City			Large City			Free
	Urban	Suburban	Open Area	Urban	Suburban	Open Area	Space
A:	129.99	117.96	97.91	130.27	116.25	98.20	97.79
B:	33.51	33.51	33.51	33.51	33.51	33.51	20.00

Hata considers six different types of propagation path; three for the small/medium size city and three for the large city where building heights average more than 15 meters (49 feet). Urban refers to downtown areas while Suburban refers to mixed dwelling residential areas. Open areas are either non-developed or only lightly developed.

Table 1.1b shows an example spreadsheet for computing allowable microwave link interference given noiselike interference sources. The first section computes the microwave receiver's noise floor based on noise figure, antenna temperature, and channel equivalent noise bandwidth. The allowable interference level is then computed based on a statement of maximum allowable E_s/N_o degradation due to interference sources. OFS antenna gain ³towards the interfering source, bandpass filter characteristics and interference bandwidth are then factored in to arrive at an allowable interference level.

3. Includes any associated cable losses.

The bandwidth of the interfering source is an important factor for OFS systems using FDM-FM modulation formats⁴; narrowband interference is potentially much more damaging. This is because the FDM spectral channelization is essentially unaltered by the narrowband⁵ FM carrier modulation process; the information content of a voice channel is carried within 6 kHz⁶ of bandwidth. The coupling factor⁷ accounts for the spectral density of the interfering source.

Table 1.1b Microwave Link Maximum Interference Analysis

Microwave Receiver NF at 290K (dB):	9.00	
Antenna Temperature (K):	300.00	
System Noise Temperature (K):	2313.55	
Noise Bandwidth (MHz):	10.00	
Receiver Noise Floor (dBm):	-94.96	
Link Fade Margin (dB):	30.00	
Required Es/No (dB):	20.00	
Min. Required Unfaded Signal Out Of Ant (dBm):	-44.96	
Faded Signal Level Out of Antenna (dBm):	-74.96	
Microwave Tower Separation (miles):	25.00	
Microwave Antenna Gain (dBi):	29.00	
Required uWave ERP (Free Space Prop) (dBm):	55.92	Watts
Microwave Transmitter Power (dBm):	26.92	0.4919
Es/No Loss From Noiselike Interferers (dB):	1.00	
Max Interference Out of the Antenna (dBm):	-100.83	
uWave Ant. Gain Towards Interferer(s) (dBi):	-5.00	
Interferer Bandwidth (MHz):	0.20	
Coupling Factor Into Microwave Link (dB):	16.99	
uWave BPF Gain at PCN Freq. (dB wrt Peak):	0.00	
Max Interference Into Microwave Ant. (dBm):	-112.82	
Resultant Unfaded C/I (dB):	67.86	

4. Roughly 83% of all OFS systems.

5. The signal bandwidth may be large, but because the FM modulation index is small, it is a narrowband FM format.

6. Two, 3.1 kHz sidebands separated by twice the FDM center frequency for that channel.

7. $10 \log (\text{Bandwidth of OFS} / \text{Bandwidth of Interferer})$

Combining these results with the Hata and/or propagation predictions, a minimum radius exclusion zone can then be computed as a function of PCS transmit power, number of transmitters, and, PCS antenna gain. Table 1.1c shows minimum exclusion radii assuming one interferer.

Table 1.1c PCS Exclusion Radii (100 kHz Interferer at 6')

		Number of Interferers:		1			
Antenna Gain Towards Microwave Link (dB):				0.00			
Tx Power (mW)	Exclusion Zone Radius (miles)						
	Small/Medium City			Large City			Free Space
	Urban	Suburban	Open Area	Urban	Suburban	Open Area	
1.0	0.23	0.54	2.13	0.23	0.53	2.09	4.96
10.0	0.47	1.07	4.23	0.46	1.05	4.15	15.69
100.0	0.93	2.12	8.41	0.91	2.08	8.25	49.60
1000.0	1.85	4.22	16.73	1.81	4.14	16.40	156.86

Table 1.1d repeats the analysis for a 10 MHz interferer.

Table 1.1d PCS Exclusion Radii (10 MHz Interferer at 6')

		Number of Interferers:		1			
Antenna Gain Towards Microwave Link (dB):				0.00			
Tx Power (mW)	Exclusion Zone Radius (miles)						Free Space
	Small/Medium City			Large City			
	Urban	Suburban	Open Area	Urban	Suburban	Open Area	
1.0	0.06	0.14	0.54	0.06	0.13	0.53	0.50
10.0	0.12	0.27	1.07	0.12	0.26	1.05	1.57
100.0	0.23	0.54	2.13	0.23	0.53	2.09	4.96
1000.0	0.47	1.07	4.23	0.46	1.05	4.15	15.69

Repeating the analysis with all parameters the same except with the interferer placed 30 feet above ground level, the results of tables 1.1e and f are obtained. Results for the small city open area Hata model are not included because it breaks down severely for large mobile antenna heights at these frequencies. Free space estimates are more appropriate under these circumstances.

Table 1.1e PCS Exclusion Radii (100 kHz Interferer at 30')

			Number of Interferers:			1	
Antenna Gain Towards Microwave Link (dB):						0.00	
			Exclusion Zone Radius (miles)				
Tx Power (mW)	Small/Medium City		City	Large City		Free Space	
	Urban	Suburban	Open Area	Urban	Suburban	Open Area	
1.0	1.01	2.30	-----	0.39	0.88	3.50	4.96
10.0	2.00	4.57	-----	0.77	1.75	6.96	15.69
100.0	3.98	9.09	-----	1.53	3.49	13.84	49.60
1000.0	7.91	18.06	-----	3.03	6.93	27.51	156.86

Table 1.1f PCS Exclusion Radii (10 MHz Interferer at 30')

		Number of Interferers:		1				
Antenna Gain Towards Microwave Link (dB):				0.00				
		Exclusion Zone Radius (miles)						
Tx		Small/Medium City			Large City			Free
Power		Urban	Suburban	Open Area	Urban	Suburban	Open Area	Space
(mW)								
1.0		0.25	0.58	-----	0.10	0.22	0.89	0.50
10.0		0.51	1.16	-----	0.19	0.44	1.76	1.57
100.0		1.01	2.30	-----	0.39	0.88	3.50	4.96
1000.0		2.00	4.57	-----	0.77	1.75	6.96	15.69

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realt

Table 1.09

TABLE 1: STATISTICAL DATA FOR 2 GHz BANDS

LAMB	RADIO SERVICE	LICENSEES	FACILITIES	CHANNEL BW	AVG. PAIR LINES	Type of Use	Sample Licenses
1950-1990 MHz Private Radio Services	Local Gov't. Including Public Safety	168	2011	5 MHz 10 MHz	19.8 million	Fixed Point to Point Circuit, Voice & Data	LA Sheriff, State of Florida, City of Dallas
	Petroleum	67	2487				Shell, Chevron, Exxon
	Power	164	3197				Georgia Power, Maryland Power Corporation, Interstate Power
	Railroads	18	895				Union Pacific, Burlington Northern, Montreal Pacific
	Others	143	668				Chickadee, Madison Postal, Proctor and Gamble
1990-2110 MHz Broadcast Services	Broadcast Auxiliary	934	7359	17 MHz	30.4 million (11 used)	Fixed and Mobile Broadcast Auxiliary - STL, DCS & DPO	ABC, CBS, NBC, Westwoodone
	Telephone/ Cellular Paging	481	6823	3.5 MHz	17.9 million	Fixed Point to Point Cellular and in use for land telephone services in the One-way Paging	Brockton Bell, U.S. West, McCom, GII
	Local Gov't. Including Public Safety	549	4052	0.8 MHz 1.6 MHz	15.1 million	Fixed Point to Point Circuit, Voice & Data	Commonwealth of Pennsylvania, State of California, Commonwealth of Virginia
2130-2150/ 2100-2200 MHz Private Radio Services	Petroleum	111	2933				Mobil, Amoco, Arco
	Power	258	3321				Pacific Gas and Electric, Southern California Edison, Allegheny Power
	Railroads	24	991				Atchafalaya Traction and Service Co. Railway, CSX, Denver and Rio Grande Western
	Others	343	1538				Maryland, University of Maryland, Hawaii State
2150-2160 MHz Common Carrier Services	Multiple Int Distribution	65	143	6 MHz	NA	Point to Point Point to Point Distribution (Multiple Carriers)	Mobitron, Comstar, Broadcast Data

Facilities

2258

6923

13,035

36,634

7.11

MICROWAVE FREQUENCY (1850-1990 MHz) USAGE
WITHIN APPROXIMATELY 35 MILES OF
BOSTON, MASSACHUSETTS

<u>Transmitter Site No.</u>	<u>Frequency MHz</u>	<u>Licensee</u>	<u>Transmit Call Sign</u>	<u>Receive Call Sign</u>
1	1905	Commonwealth of Massachusetts	KCB88	KCB89
2	1875	Commonwealth of Massachusetts	KCE99	KCJ22
3	1955	Commonwealth of Massachusetts	KCJ22	KCE99
4	1875	Commonwealth of Massachusetts	KDB75	KDS76
5	1935	Boston Edison Company	KPO72	WIA243
6	1915	Algonquin Gas Transmission Company	KWB54	KWB55
7	1965	Algonquin Gas Transmission Company	KWB55	KWB54
8	1975	Algonquin Gas Transmission Company	KWB55	WAJ79
9	1855	Algonquin Gas Transmission Company	WAJ79	KWB55
10	1885	Algonquin Gas Transmission Company	WAJ79	WAJ81
11	1915	Algonquin Gas Transmission Company	WAJ79	WAJ78
12	1695	Commonwealth of Massachusetts	WAM37	KDB76
13	1870	MIT Lincoln Laboratories	WNC462	WNEX21
14	1975	Prime Computer, Inc.	WEJ778	WEJ779
15	1895	Prime Computer, Inc.	WEJ779	WEJ778
16	1985	Boston Edison Company	WIA243	KPO72
17	1925	State of Rhode Island	WJB64	WJC97
18	1885	State of Rhode Island	WJB70	WJC96
19	1895	State of Rhode Island	WJB70	WJC97
20	1905	State of Rhode Island	WJB70	WJB69
21	1855	Blue Shield of Massachusetts, Inc.	WNEH993	WNEH9
22	1885	Blue Shield of Massachusetts, Inc.	WNEH994	WNEH9
23	1935	Blue Shield of Massachusetts, Inc.	WNEH994	WNEH9
24	1965	Blue Shield of Massachusetts, Inc.	WNEH995	WNEH9
25	1985	Public Service Company of New Hampshire	WNEX380	WNEX1

Table 3

Channels	Per Channel RMS Deviation (KHz)	Average Channel Power(dBmQ)	Total rms Deviation (KHz)	f_L Baseband Frequencies (KHz) Lowest	f_H Highest	Modulation Index	Bandwidth (KHz)
1.9/6.7 GHz Bands							
780	140	-19.6	409	60	3284	0.125	10
600	140	-15.0	610	60	2540	0.240	10
400	200	-15.0	779	60	2044	0.380	10
300	200	-15.0	616	60	1300	0.470	10
120	200	-15.0	464	60	552	0.840	5
120	200	-15.0	464	60	552	0.840	5
300	175	-19.6	319	60	1300	0.245	
"Grandfathered" 1.9 GHz Band							
600	80	-15.0	303	60	2540	0.15	0
420	160	-15.0	503	60	1800	0.32	0
2130 MHz-2150 MHz and 2100 MHz-2200 MHz Band							
132	47	-19.6	66	12	552	0.12	1.6
96	47	-15.0	104	12	408	0.25	1.6
72	60	-15.0	126	12	300	0.42	1.6
48	25	-15.0	50	12	204	0.24	0.8
24	42	-15.0	70	12	108	0.72	0.8
12.5/13.0 GHz Band							
1200	140	-15.0	866	564	5772	0.15	20/25
600	200	-15.0	871	60	2540	0.34	20/25
300	200	-15.0	616	60	1300	0.47	20/25
300	200	-15.0	616	60	1300	0.47	10/12.5

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Table A-1 Modulation Parameters

ATTACHMENT C

As Personal Communications Services evolve, Bell Atlantic is focusing on developing access services it can offer over open interfaces to PCS service providers. The PCS service providers offer Personal Communications Services to the end users. Therefore, the PCS service providers are the "customers" for the access services; the PCS users are the "customers" of the PCS service provider.

PCS service providers would use the access services offered by Bell Atlantic to take advantage of our network infrastructure of signaling, transport, switching and intelligent network capabilities. Each PCS service provider would use the access service that best compliments their own capabilities. For instance, one PCS service provider may possess only a small portion of the functionality required to provide a PCS end-to-end service. Such a provider would expect the Bell Atlantic network to offer a great deal of functionality through the access service. On the other hand, a different PCS service provider may have a complex network that supports much of the required end-to-end functionality. They would opt for an access service with only a subset of the functionality offered to the first PCS service provider.

Bellcore and the Bell Operating Companies developed a document that identified five access service alternatives. Bell Atlantic has focused on four of these access services, but has modified them to take advantage of our Advanced Intelligent Network capabilities. Fig. 19-1 shows the possible access service interfaces.

The network, or "N", interface is a connection service to a wireless PCS service provider who has the capabilities to provide call control processing, radio

management, and subscriber information storage. This access service offers signaling and transport to a wireless PCS service provider with switching capabilities. Through the N interface, Bell Atlantic will provide translation and routing functions so that calls for PCS subscribers are delivered to the appropriate wireless PCS service provider network. The PCS service provider will use the N interface when a user originates a call that must be delivered outside of its network. The N interface will also be used when a call is delivered by Bell Atlantic for a user who is currently being served by the PCS service provider. (Wireless PCS service providers that subscribe to the N interface will most likely take advantage of the Advanced Intelligent Network capabilities through a combination of the N interface and the data, or "D" interface. See the discussion on the D interface for more detail.)

The controller, or "C", interface serves PCS service providers who have the capability to provide radio channel control and possibly some local data storage. All switching functions and call control functions are supported in the Bell Atlantic network because the PCS service provider's network does not contain complete local switching systems. The Radio Port Control Unit (RPCU) may have the capability to provide hand-off. This interface is between the Bell Atlantic Central Office switch and the PCS service provider's RPCU. Communications between RPCUs may be supported by the Bell Atlantic network.

The port, or "P", interface is intended for a wireless PCS service provider with a minimum amount of network functionality. In this scenario, the PCS service provider owns and operates the radio ports and provides the air interface to the wireless handset. Any communication between the radio ports is supported via the Bell Atlantic network. The P interface provides all the functionality included in the N and C interfaces, as well as some radio management and hand-off.

The data, or "D", interface is used by PCS service providers that want to take advantage of Bell Atlantic's Advanced Intelligent Network capabilities. Through the D interface, the PCS service provider's network accesses the centralized data in the Bell Atlantic network. Examples include PCS customer location updates, PCS customer authentication, and PCS customer service profile access. A PCS service provider will most likely subscribe to either the P, C, or N interface and some number of services provided over the D interface.

Bell Atlantic's vision for a PCS architecture is in Fig 19-2. The different interfaces are overlaid on this architecture.

The dotted line between the RPCU and the AM indicates the D interface for a PCS service provider subscribing to the C interface. This is also a signaling connection through the CO switch.

Finally, the dotted line between the Wireless Network and the Signal Transfer Point (STP) represents the D interface for a PCS service provider subscribing to the N interface. Ideally, this would also go through the CO switch. However, limitations in the ISDN-SS7 interworking at the switch prevent such a solution in the near-term. As a result, the D interface is directly into the SS7 network via the STP.

¹The Access Manager (AM) is a new Bell Atlantic network element introduced to provide subscriber information storage and wireless call control.

Analysis of Large Reuse Factors

**Required by
Narrowband Systems**

Subject: Comments on "Low Power Wireless PCS Spectrum Estimates", by Andy McGregor, TE/92-1-14/003

Author: Logan Scott

While we agree with the analysis approach taken by Andy, the following additional considerations could significantly alter the results:

- Propagation Coefficient
- Operation in a Three Dimensional Lattice
- Wireless Market Penetration

Propagation Coefficient

In the 800-900 MHz mobile radiotelephone services band, propagation is usually well described as Rician fading with a propagation coefficient of between 3 and 4. This means that on average, signal strength falls off as the 3 or 4 power of range.

In Andy's paper, he used a propagation coefficient of 3.34 and indicated a doubling of capacity if the propagation coefficient is raised to 4. In general, lowering the propagation coefficient reduces capacity by forcing more infrequent frequency reuse.

In the short range and indoor environments, propagation coefficients are usually much smaller. As an example, in *Fig. 20-1*, the mean propagation coefficient is 2.18, averaged over all factories. In Line Of Sight (LOS) geometries, the mean propagation coefficient is typically even smaller, as small as 1.49. Similar observations were made by Schilling et.al in [SC91] except using a 1956 MHz center frequency.

Operation in a Three Dimensional Lattice

In multistory buildings, three dimensional reuse patterns need to be considered for microcellular architectures. Signals from the adjacent floors can interfere with each other. Three-dimensional frequency reuse patterns have been studied by Porter [PO85] using crystal lattice structural models. His basic conclusion is that frequencies can not be reused as often because D/R^2 grows only as $N^{1/3}$ in three dimensional lattices.

1. Abstracted from [RA69]

2. D/R is a measure of the separation between same frequency cells. D is the separation between same frequency base stations and R is the radius of a cell. Larger D/R values reduce cochannel interference.

His most efficient packing structure, a closepacked lattice structure yields:

$$D/R = (8/3)^{1/2} N^{1/3}$$

Solving for N:

$$N = (D/R)^3 / (8/3)^{1.5}$$

Assuming that only the nearest 6 cochannel users contribute to the interference picture:

$$(S/I) = (1/6) (D/R)^\alpha$$

Solving for D/R and substituting:

$$N_{3-d} = (6 S/I)^{3/\alpha} / (8/3)^{1.5}$$

The corresponding two dimensional formula, eqn 1 in Andy's paper is

$$N_{2-d} = (6 S/I)^{2/\alpha} / 3$$

These formulas are not particularly accurate for small N configurations but serve to illustrate the general trend. Fig. 20-2 compares frequency reuse factors for 2-d and 3-d hexagonal lattice structures assuming a propagation coefficient of 2. For a given S/I, the 3-d architectures require substantially more frequencies; particularly for narrowband modulation formats requiring high S/I. As an example, consider the results of Fig. 20-3 where the propagation coefficient is set to 3.34, typical of the AMPS cellular telephone system.

In a two dimensional lattice, if the threshold C/I is 15 dB, an N=7 cell architecture is permitted. The same situation, translated to a 3-dimensional lattice, requires an N=25 cell structure. Capacity per cell is reduced by a factor of $25/7 \approx 4$ since each cell is given only 1/4 as many frequencies to use.

Fig. 20-4 plots the ratio N_{3-d} / N_{2-d} as function of required C/I for selected propagation coefficients. Systems requiring high C/I are most strongly impacted in the transition to a three dimensional lattice.

The above conclusions are based on an assumption that signals propagate equally well between floors as intrafloor. PCNA [PC92] measurements at 1956 MHz show excess interfloor losses of 11 to 22 dB through one floor, 25 dB through 2 floors, and 30+ dB through more floors, depending on construction. Although this alters the frequency reuse problem, it doesn't reduce it to a two dimensional lattice; distances between floors are usually small compared with the cell size.

Wireless Market Penetration

Some of the indoor scenarios indicate very high user densities per m², typical of current wireline operations. We question whether wireless operations will penetrate the indoor market this deeply. We expect about 15% market penetration at most. Larger cell sizes would be expected with potentially greater spectrum requirements.

References

- [Mc92] Andy McGregor, *"Low Power Wireless PCS Spectrum Estimates"*, TE/92-1-14/003 obtained at March 4 Telocator meeting.
- [PC92] ??, *"PCN America Propagation Testing Methodology and Results"*, TE/92-3-3/020 obtained at March 4 Telocator meeting.
- [PO85] P.T.Porter, *"Relationships for Three-Dimensional Modeling of Co-Channel Reuse"*, IEEE Transactions on Vehicular Technology, May, 1985.
- [RA89] T.S.Reppaport, *"Indoor Radio Communications for Factories of the Future"*, IEEE Communications Magazine, May 1989.
- [SC91] D.L.Schilling, *"Broadband CDMA for Personal Communications Systems"*, IEEE Communications Magazine, November 1991.

INTRODUCTION AND SUMMARY

Based on work begun in 1987, Omnipoint has developed an Asymmetrical Two-way Wireless Network ("ATWN") which will provide a low cost, highly spectrum efficient method of

delivering two-way data communications to the current generation of mobile computing devices such as portable computers, new pen-based computers, industrial portable data devices and the expected class of consumer "nomadic devices" such as those recently described as being under development by Apple Computer.

What differentiates Omnipoint's two-way system from all other known two-way wireless services and proposals is that it is able to combine existing and future low capacity wireless links with a high capacity channel to produce what appears to the user like a full duplex network. The only difference from a user's perspective from a full duplex network is that the data speeds vary by directions. The speed from the remote unit to the host will be slow (using ARDIS, RAM or cellular frequencies) while the speed from the host to the remote will be very fast (using the 1850-1990 MHz band). This fits most real world applications where a relatively small number of requests to a host results in a much larger amount of data being sent from the host in response. Indeed, research has shown that a ratio of 100 characters bound from the host to the remote for each character bound to the host from the remote is a typical situation. In many cases the ratios may be much larger than that.

ATWN should be distinguished from simulcast data delivery systems such as the Data Broadcasting Service which Omnipoint is

developing with McCaw and Oracle. Such systems perform an equally valuable but different service from the data on request function of ATWN.

Spectrum efficiency is at a premium in the ATWN system. It uses any frequency available which co-exists with Operational Fixed Service ("OFS") users. Indeed, it is also compatible with a voice-based PCS system. This is because it delivers data to every cell using different frequencies and the cells are 60° sectorized so that data can even be delivered to every cell sector using a different frequency. Because of this sectorization, the system will automatically select an OFS frequency which is not in use within the applicable interference-free distance.

CORPORATE BACKGROUND

Omnipoint is a five year-old company specialized in developing spread spectrum communications systems for a variety of end user applications requiring wireless voice, data and video links. Omnipoint is a privately held company with financial backing from the investment banking firm of Allen & Company, which was the founding investor of MCI Communications, Inc. and Digital Switch Corporation.

With over 300 person-years of experience in spread spectrum technology, Omnipoint has assembled one of the most knowledgeable teams of engineers and scientists in the industry. Accomplishments of Omnipoint personnel include:

- o Development of the first produceable spread spectrum system.
- o Design of the U.S. Navy Fleet Satellite Communications network.
- o Design of both hardware and software of the "next generation" National Security Agency encryption chips.
- o Authoring the first textbook on spread spectrum theory and application.

In addition to voice products, Omnipoint also provides wireless data communications products to companies such as the world's largest supplier of communicating hand-held terminals. Additionally, teamed with Texas Instruments, Omnipoint was chosen by the Chicago Board of Trade and the Chicago Mercantile Exchange to develop a prototype communications system for their automated commodities trade reporting system.

THE PROBLEM AND THE SOLUTION

Portable computers are currently the most rapidly growing component of the computer industry. The "next generation" portable computers will be the pen-based computer now in development. Forecasts for the demand for pen-based systems vary but most projections state that in a relatively short time frame there will be millions of such devices in the marketplace. Consumer "nomadic device" forecasts are even greater. Some forecasters project that as many as 60 million such units may be in the hands of consumers in the next decade. The bulk of the usage of such devices when engaged in two-way communications will be to request data from a host network.

Examples of the type of uses referred to are as follows:

1. Personal or Private Data Base Access. A user needs to access his own remote host computer for queries such as checking inventory levels, credit reports, status of work in progress, current pricing and checking host-based electronic mail when the user is in the field.
2. Public Information Services. Growing numbers of jurisdictions provide remote access to public information such as real estate transactions, building codes, court calendars, meeting schedules and other forms of information which may be of interest to the public. Cost-effective portable access to this kind of information will increase its value to the citizenry.
3. Data Upon Request. When the desired data is a document or file of substantial size, other existing and proposed wireless networks make the retrieval of such lengthy documents slow for real world use and/or extremely expensive. For example, at current ARDIS pricing, transmission of a single one megabyte file would cost about \$800 and would take nearly an hour to transmit under the best of conditions. ATWN could accomplish the same transfer in 16 seconds at a much lower cost. Examples of applications for this kind of data upon request includes retrieval from a central host source of police material such as fingerprints, photographs and case files; fire department use such as building plans, hydrant locations, maps; hazardous material inventories and first-aid instructions;

corporate, academic and government uses, such as retrieval of maps and geological information, customer records, price and policy changes, architectural drawings, etc.; and transfers of any data in the form of computer file such as a word processing document, spread sheet or even computer software, thus providing the remote user with at least theoretical access to everything on his host computer.

Many computer users are used to the above types of applications in a stationary mode on a local area network or a wide area wireline network. These users will be disappointed by many of the slower speed symmetrical offerings that are in the marketplace or proposed for mobile usage. We believe that ATWN comes the closest to replicating a wireline-style access over a wide area to wireless device. User expectations will also be further increased by the current rapid movement from character base operating environments such as MS-DOS to graphical environments such as Microsoft Windows. Indeed, all pen-based computing will be graphical in nature.

Omnipoint's solution, as described in more detail below, involves integration of existing slow speed networks for mobile-to-host communications (e.g., ARDIS, RAM or cellular) with a high speed outbound link in the 1850-1990 MHz band from the host network. The method for achieving high speed outbound communications in the 1850-1990 MHz band, and for integrating

the two links into a transparent error free, full duplex transport layer is a proprietary protocol that is designed to take advantage of state-of-the-art capabilities, including the use of a highly intelligent and computationally intensive data center to integrate the two links.

By designing a custom protocol reflecting current hardware capabilities at the remote terminal, Omnipoint has been able to achieve exceptionally efficient use of the outbound spectrum, reducing by as much as 90% the data that needs to be transmitted on a transmission error condition, as compared to older protocols. This has been done in combination with an innovative and proprietary error recovery mechanism designed specifically for this hybrid application in a wireless environment.

TECHNICAL DESCRIPTION

The objective of ATWN is to provide wide area distribution of high speed, nominal 600 kbps data to mobile units without disturbing existing OFS users in the 1850-1990 MHz band. To this end, Omnipoint proposes a modem and network consisting of a unique low power direct sequence spread spectrum system coupled with a two-way low speed channel.

An array of low power transmitters¹, spaced approximately one mile apart,² will provide data distribution services at a data rate of 500,000 bits per second on a co-existence basis with OFS users. Sharing with OFS will be accomplished using

1. 0.100 watt nominal ERP.

2. Local spacing can be increased or decreased in accordance with OFS interference engineering studies by altering transmit ERP.

a frequency avoidance strategy combined with sectorized transmit antennas. In difficult situations, orthogonal polarizations³ will be examined as an approach to reducing interference into the OFS receiver. Specific frequency and antenna parameters will be engineered on a site by site basis to ensure OFS system integrity.

Because mobile units do not transmit in the OFS frequency band, there is no "Rogue" transmitter problem such as would occur in a two-way in-band system.

Furthermore, because the system uses sectorized antennas, it can also operate at frequencies not usable by PCS services because of OFS interference considerations.

ATWN does not require a specific frequency allocation but instead will use frequencies on a space available, licensed basis. Requested transmission bandwidth is 10 MHz, which is consistent with current OFS channelization policies.

System Description and Sharing Approach

Recognizing from the onset that the ATWN network must coexist with current OFS users, Omnipoint has specifically engineered its system to have minimal impact on OFS operations. Key features to promote sharing include:

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3. The system to OFS propagation path is basically tower to tower and polarization preserving. The system to mobile transmission paths normally have significant cross polarization coupling due to multipath; usable energy will be received.

- o Direct sequence spread spectrum for low spectral density, reduced sensitivity to multipath, and, mechanism for three-way data transmission.
- o Sectorized transmissions to avoid jamming OFS.
- o Three-way data transmission to reduce transmission power.
- o Data request queries carried over cellular or PCS channels.

Referring to fig. 21-1 the system uses multiple base stations in an approximately triangular grid to cover the service area. Each base station site consists of six transmitters, each separately driving a 60° sector antenna.⁴ Although not required, the frequency of each transmit sector can be different if necessary to minimize interference between this system, OFS and PCS services. The data transmission rate can be independently set from cell to cell.⁵

In any given triangular service cell, the three base stations that form the corners of the triangle (a) send high speed data using appropriate 60° sector antennas, (b) use different spreading codes and (c) potentially use different frequencies. Within the data stream, block interleaving and

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4. For aesthetic reasons, conformal mount, flat antennas mounted on the sides of buildings may be used in some areas where obtaining zoning for tower mounted antennas is difficult or economically undesirable.
 5. Different sectors of a base station may be transmitting at different rates.

convolutional encoding is also used to further mitigate fading and interference effects. An additional low rate, base station/sector identifier data stream unique to each transmitter is included to facilitate mobile unit location determination and data transmission query processing.

The data on the outbound transmission in each triangular cell will be different. Since each sector antenna will need to transmit a different data stream, the requirements are six times that of the data broadcast service.

At the mobile receiver, because each transmitter can also use a different spreading code, the signals can be separated and processed independently prior to data system combining. The Omnipoint receiver independently despreads the three signals, performs soft decision data demodulation and then combines the data streams prior to convolutional decoding. Code based, variable delays are introduced to synchronize data streams prior to combining.

Base stations are easily and precisely synchronized using the Global Positioning System. Including base station position in the data stream, the user can locate his position to an accuracy of about 30 feet by measuring pseudorange to each of the three transmitters⁶. As a further benefit, the user can measure time within an accuracy of about 30 to 100 nsec. This

6. GPS does the same thing only using a fourth channel so it can measure altitude.

feature will be extremely useful in synchronizing other systems, and will be especially offered for synchronizing PCS base stations.

Advantages associated with triple transmission and spread spectrum formats include:

- o Significantly reduced sensitivity to signal shadowing effects caused by buildings, hills, etc. ATWN is a reliable data transport medium with a high percentage of coverage.
- o Mitigation of multipath fading effects and enhancement of error correction coding performance. Triple transmission provides space diversity. Spread spectrum provides frequency diversity.
- o Use of frequency selection diversity when all three transmitters are not using the same frequency or interference is encountered.

All of the above factors combine to significantly reduce required transmit power and hence the potential for OFS interference. Referring to *figs. 7-8*⁷ when transmitting in the direction of an OFS receiver, if the same frequency is to be used, an exclusion zone must be established. The required exclusion range is a function of transmit ERP and allowable OFS receiver threshold elevation. Because Omnipoint uses a

7. A worst case, free space, line of sight propagation model was used in generating this figure.

noiselike, spread spectrum signal, the effect of ATWN transmissions on OFS is to increase the apparent noise figure of the receiver. Referred to as threshold elevation, this apparent noise figure increase has the effect of reducing ES/No.

TSB10-E, the governing standard for OFS interference, requires no more than 1 dB of threshold degradation. Referring to *Figs. 7-8* a five mile exclusion zone is needed for a 0.100 watt ERP transmission towards the OFS receiver when using the same frequency. Relaxing the threshold elevation standard to 6 dB, a 0.100 watt transmitter requires an exclusion zone of 2.3 miles. While the ATWN system can operate within the constraints of TSB10-E, Omnipoint notes that most OFS links are extremely over engineered.⁸

System Performance

To maximize deployment flexibility, the ATWN system is designed to permit all sectors and transmitters to operate on any frequency. In computing the effects of mutual interference within the system, worst case conditions are assumed where, for coexistence reasons with OFS microwave base stations must use the same frequency. It is further assumed that the receiver is located in the fringe transmission area for the cell. This yields a worst case scenario for cochannel interference. A

8. A COMSEARCH study of all Houston OFS links showed average fade margins of 54.4 dB. This corresponds to a mean outage time of 1.3 seconds per year for a 25-mile link. A 5 dB threshold elevation would lower fade margin to 48.4 dB; outage time increases to 5.2 seconds per year.

Hata, large city urban propagation model is used to estimate path loss from sector transmitters to mobile units. Recall that Omnipoint uses worst case free space loss from the transmitters to the OFS towers when calculating potential interference to OFS. Thus, conservative assumptions are used in each case.

Fig. 21-3 depicts maximum data rate as a function of base station separation for 1, 2 and 3 signal combining assuming receivers are located 6 feet above ground level (AGL). The 0.100 watt ERP sectorized transmission antennas are located 100 feet AGL. When base stations are close together, data rate is dominated by mutual interference considerations while at wider separations, the system is noise limited. In high OFS density areas, a triangular grid of transmitters 1 to 2 km apart provides a 600 kbps data rate.

OFS interference considerations may force one or more of the three transmitters on a triangular cell to operate at difference frequencies, or not transmit at all in extreme cases. The receiver will have the option of selecting any of the available transmission frequencies based on local propagation characteristics and received $S/(1+N)$. We also note that where three frequency diversity is available, a propagation path better than that predicted by Hata is likely; data rate estimates for the 1 signal combining case are rather pessimistic.

Because of the hybrid nature of the network, the availability of the inbound low speed channel can be used. Independently set data transmission rates from cell to cell can

even be switched in real time according to user originated service requests. A user experiencing good quality reception could request a higher data rate if total traffic warrants.

In establishing the cell structure, there is a tradeoff between power cell spacing and data rate. During initial service offerings, Omnipoint may choose to provide a lower data rate on the outbound channel with wider base station separations. As demand grows, more base stations can be added to the network in a cell splitting arrangement. Alternatively, in low OFS density areas, it may be appropriate to increase transmit power.

Figs. 21-4 TC 21-6 document increased base station separations achievable by raising ERP to 0.500 watts, 1.000 watts and 100 watts, respectively. Peak data rates at close separations are not affected since performance is S/I limited to these regions.

Fig. 21-7 demonstrates how the ATWN system conducts self-interference distance calculations so as to avoid self-jamming transmissions. This shows the worst-case scenario.

DISTINCTION AND ADVANTAGES OF ATWN CONCEPT

As described above, the ATWN concept makes use of a high speed outbound link with the use of an integrated back channel which enables a large amount of data on a customized basis to be delivered to the user in the field in an extremely spectrum efficient manner.

This concept should be distinguished from other services which are contemplated by Omnipoint and others which use a simplex link without the integrated back channel. This latter service can be described as a Data Broadcasting Service ("DBCS"). Omnipoint is developing such a concept in a joint undertaking with Oracle and McCaw. This concept uses an $N=1$ (i.e., the same frequency) in every sector and cell and is thus a simulcast system. In other words, the same data at the same time is transmitted on every cell in a particular city. This type of service is for real time data such as low cost E-mail delivery and for electronic information and other software publishing where the same data is going to millions of users. This is an invaluable service for which there is great demand. ATWN is simply a different service meeting different needs.

In contrast, the ATWN outbound link uses any frequency available in the 1850-1990 MHz band so that it can co-exist with OFS and with PCS. The cost of the ATWN network will be several times higher, but it will be used for totally different applications. ATWN delivers different data to every cell and can even deliver different data to each of the six sectors in each cell, all using different frequencies. Thus, this two-way system is for a completely different application, i.e., data on request. Other differences include the type of transmission network in that more cells and many more frequencies are utilized, although in a spectrum efficient manner. There is a different network protocol as described in detail above whereas

DBCS is a streaming simplex protocol from a single data center. Omnipoint's hybrid two-way is an asymmetric duplex protocol interconnecting two networks and in all likelihood more than one data center. Finally, the modems are very different and the pricing is dramatically different in that data broadcasting spreads the cost over many recipients.

A good analogy between DBCS and ATWN is that between conventional paging and cellular. In both of those cases, the simplex-only product uses a very low-cost receiver and a relatively inexpensive transmission network to provide a low-cost service to a very large market. The duplex offering anticipates considerably more expensive equipment, a large investment in transmitters, a very high and flexible level of functionality with commensurately higher costs and fewer, although still large, numbers of users. The simplex network is likely to be best utilized by a city-wide simulcast using a few towers. This, of course, requires significant coordination with the OFS users so as not to conflict with their frequencies. An ATWN network, in order to achieve the necessary capacity within the constraints of a frequency allocation, will need to be designed to provide unique data in each cell. This will require a frequency agile receiver and substantially more towers to allow for co-existence with OFS licensees. Omnipoint believes that markets exist for both classes of service but it should be clear that they are inherently different businesses.

The data on request aspect of ATWN is a unique, efficient and cost-effective method of accomplishing this growing need for data in a mobile context. Private users, police, utilities, governments, etc. all will increasingly need rapid access to data in a low-cost and efficient manner. These private requests consist of accessing personal, corporate or government files, not a single centralized data base. The ATWN concept allows for a lower speed per cell but different data can be sent from each cell and from each sector of a cell. The remote instrument can tell the network which frequency to use to send data to whichever tower is closest. This intelligence enables the frequency agile receiver to utilize the network and the frequencies available to it in an extremely efficient manner. Moreover, the speed of the outbound data from the host network back to the receiver in the field is far faster than any other method now being utilized or currently proposed. For example, most modem rates run between 2,400-19,200 bps. The ATWN concept will be as high as 400-500 kilobytes per second.

Since different frequencies will be utilized, each cell using the ATWN concept will need less spectrum than other data transmission systems. There is always a non-interfering OFS frequency available in each sector of each cell. The reason that there is no interference is that there will be no mobile uses in the 1850-1990 MHz frequency band in the ATWN proposal. This is because the communications from the mobile unit are not

on these frequencies. The OFS frequencies are used only for the outbound links. They are used on an interference-free sectorized basis. Moreover, the frequencies that will be utilized by the sectorized cells will be frequencies that PCS cannot use because the omni-directional aspect of their transmissions will cause interference to OFS. The spectrum choice that PCS makes will have to be on a non-OFS interference basis, thus allowing the ATWN system to efficiently use the interstices in this frequency band.

In conclusion, what Omnipoint has done with the ATWN concept is to design a system to meet an identifiable and growing demand for the provision of a high speed, low-cost, two-way transmission of data on request.

PREFACE

The system features and options designed into our system and proposed for use in the "Emerging Technologies Band", especially in the 1850-1990MHz portion, are the result of an enormous amount of research into the actual operating characteristics of the incumbent microwave users. In fact, our approach to sharing was to put ourselves into the shoes of an incumbent and ask what we would expect

and demand, what we would be willing to agree to, and what we would be willing to negotiate if confronted with a prospective PCS provider.

The PCS systems which we have been tailoring for use in this band and have now reduced to operational microcells and pocket phones reflects the evaluation of an enormous number of tradeoffs. The system was designed not only to provide optimal efficiency for both outdoor, wide area PCS as well as indoor, private premises PCS, but it was designed specifically to coexist with other users, particularly the OFS incumbents.

In this proceeding which is wrestling to identify not just innovation but commercially deployable innovation, we feel it is important to reiterate that we have operational, spread spectrum, pocket phones and wireless systems operating in the 1850-2200 MHz band that incorporate the critical system features discussed in our Pioneers Preference. We have been, and continue to be the only supplier of handheld, direct sequence, spread spectrum phones for PCS experimental license holders. In fact, over the past three years Omnipoint has been the only U.S. company other than Motorola to supply PCS handsets of any kind to experimental license holders. (Motorola has been supplying CT2 equipment at various frequencies).

We emphasize this point because there are huge differences between a) principles of operation that can only be modeled and simulated; b) what can be demonstrated in a prototype that has no constraints on size, power consumption, cost, or mass producibility; and c) what can be achieved in a handheld RF product. We also suggest that our proximity to commercialization be viewed as an indicator of

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how long we have been at this as well as the fact that we are far beyond the minimal "technical feasibility" stage for consideration of a Pioneers Preference. With the exception of CT2 based systems, we believe we have the only PCS system which will be commercially fielded this year. Recall that CT2's technology dates back to the original developments of PA Consulting and Ferranti in the U.K. in 1982.

As we indicated in our comments with respect to this PCS Pioneers Preference proceeding, in seeking a preference we are not asking the FCC to implicitly set a standard using our particular technology solutions. Rather we believe multiple parties deserve a preference, including those proposing alternative approaches. We believe the market will inevitably sort out multiple standards, as it has in the computer industry and the wired PBX industry. Just as personal computing embraced different de facto standards for different needs -- MacIntoshs, IBM compatibles, UNIX, VMS, etc -- personal communicating will also seek out different solutions for different applications.

With respect to the Pioneers Preference, we believe we have contributed in many innovative ways to a vision of the meaning of PCS distinct from other services which are inherently predicated on different technical and operating assumptions (such as cellular). The many years and millions of dollars we have invested in original research into multiple sharing technologies and solutions to the problem of providing both in-building as well as outdoor PCS has "brought out the capabilities or possibilities of the technology or services" of PCS and "has brought them to a more advanced or effective

state". Although we are often thought of as a spread spectrum pioneer, our spread spectrum approach proposed for PCS in the frequency bands under consideration was derived by defining our view of the service.

As we will show below, our vision of the PCS service resulted in a very different approach to using spread spectrum than any other spread spectrum based system proposal.

In its simplest outline, our vision of a PCS service required a solution which would:

Allow for independently owned and operated base stations on private premises such as in offices and residences and interconnected to existing switching platforms;

Provide for direct interconnection to the existing PSTN to leverage the enormous investment in infrastructure including ubiquitous access and backhaul, the Advanced Intelligent Network's (AIN) features, and the ability to provide most of the features and services which make "personal communications" "personal";

Provide for the possibility of extended backhaul through infrastructures of various media, including fiber optics and coax such as those used or being planned for the Cable TV networks, before complete demodulation and processing of the signals;

Provide the consumer with the option of using a single handset with either private or public networks;

Allow for early deployment through using technologies specifically designed to allow sharing with the incumbent OFS users.

While these goals may seem intuitively obvious to some people today, there are many technologies proposed for introducing PCS in the U.S. that were neither designed to achieve these goals nor could be used to achieve them.

It is important to recall that not one of the publicly known technologies which were in use or even in development prior to 1989 was designed to achieve all of the above goals or could do so now -- CT2, CT3, DECT, GSM, Analog AMPS, IS-54 TDMA, etc. .

PCS service concepts and spread spectrum techniques both had their public "awakenings" in 1989. Although Omnipoint had spread spectrum prototypes operating in its laboratory screen rooms in 1987, the general explosion of interest in developing spread spectrum systems only began in 1989 as the capacity and sharing limitations of traditional RF technologies became painfully clear. The sudden explosive demand for handheld cellular phones once they reached certain size and price thresholds and the need for much larger amounts of spectrum to meet the market projections for a myriad of new wireless applications, became the blades of the scissors which cut through traditional thinking on both technology issues as well as spectrum reallocation issues.

Spread spectrum, however, is not one technology. In fact it is an information theory whose insights can be exploited in radically different physical implementations. CDMA-only systems such as those

proposed by Qualcomm, SCS Mobilecom, and others are very different from Omnipoint's, not just in their technological approaches, but in their ability to provide certain PCS services. For example, Qualcomm's system was designed for the needs of cellular operators and reflects the goals and limitations which that focused purpose gave them. As discussed below, Qualcomm's system will not meet the service goals we set for ourselves (as defined above) without sacrificing its capacity gains. SCS Mobilecom's approach also reflected a different vision of the PCS service concept. These are not necessarily criticisms, nor are we saying they don't deserve recognition for their own achievements and visions of PCS. But we feel it is critical for the Commission and the communities affected by PCS, including the OFS incumbents, to understand the significant differences between various PCS technologies and architectures and their regulatory implications.

The premise of Omnipoint's pioneers preference request is that our original developments and experimentation have far reaching significance for three broad areas of immediate concern to the PCS licensing procedure:

Regulatory Reallocation Options

Service Definitions and Spread Spectrum Technology Choices

Definition of Interference as the Key to Introducing PCS

I. Regulatory Reallocation Options

The Subtle Interplay Between Technology and Regulation (Round II)

Our position has been that defining the meaning of the words primary and co-primary, which means specifying the definition of interference, is the key to introducing PCS into the Emerging Technologies Band.

Different technological approaches have different abilities to coexist. We do not believe that the Commission should attempt at this time to pick specific technologies. But the rules should recognize the radical differences in sharing capabilities among different approaches and both implicitly and explicitly reward techniques which facilitate greater sharing.

Equitable rules governing the allocations for different "Emerging Technologies" and services and the process for relocation and negotiation of OFS incumbents will be derived from the interference and operating characteristics of specific proposed PCS technologies.

Omnipoint would also welcome an objective, balanced, "spectral efficiency" criteria for Emerging Technologies if the complexities of agreeing on the assumptions could be resolved. Omnipoint's system was designed to optimize capacity relative to the real world requirements for sharing and economic viability. We have tried in various industry forums and standards committees to come up with mutually agreeable guidelines for defining spectral efficiency, but unfortunately we are now convinced such a standard can not be created at this time.

Real world "spectral efficiency" is a very complex concept and involves far more than a "bits per Hertz per square kilometer" measurement. One has to take into account a myriad of factors including the actual service application and cell sizes, whether it involves handoff, whether it is an in-building application with severe multipath and three dimensional reuse requirements, whether the methodology will allow for independent ownership and operation of equipment, as well as the cost, complexity, and time to market issues so critical to the deployment of consumer products and commercially viable network infrastructures.

In addition, with respect to use in the "Emerging Technologies" band, one has to factor into any "spectral efficiency" equation the ability for the methodology to share with the OFS users.

Consequently, although an understanding of a specific PCS architecture's capacity relative to its limitations could be a major topic during comparative hearings if that method is used for determining licenses, we see no way to codify spectral efficiency in the abstract. To a large degree, awarding multiple preferences for different geographic areas for competing technologies will both spur continued innovation while forcing the license holder to balance off the benefits of additional innovation against the economic realities of the marketplace and the benefits of industry standards.

Implications of Interference Analysis for Spectrum
Allocations and the Process for Relocating Incumbent OFS Users
Conclusions From Comipoint's Experiments Affecting Public Policy

The potential for interference to OFS systems from PCS systems is very real, but varies dramatically depending on the PCS application and the PCS RF architecture. As documented in our Pioneers Preference request and in our experimental reports, even 90 degrees outside the beampath of a microwave tower, narrowband PCS systems cause significantly more interference than a 10MHz spread spectrum PCS system, all other assumptions being equal (power levels, propagation assumptions, degrees outside the beampath, etc.)

The heart of the regulatory issue involving sharing is to define exclusion zones around the microwave towers that vary in size depending on the interference characteristics of the PCS technology proposed for deployment. As long as a PCS operator's chosen technology is used outside that technology's exclusion zone, the PCS operator only needs to inform and coordinate with the incumbent OFS.

The rules governing PCS should carefully detail the definitions of interference, sharing, primary, co-primary etc in such a manner that they implicitly and explicitly recognize the differences in sharing capabilities between various PCS technologies and architectures. By carefully setting this up at the beginning, the Commission can then remove itself from both the process of setting PCS modulation standards and the drain of case by case territorial conflicts.

The specific PCS application and the PCS RF architecture proposed by any operator will therefore dictate when a PCS operator

will have to negotiate with specific OFS incumbents as opposed to simply informing and coordinating with them. (In the extreme case of unlicensed PCS applications, negotiated national band clearing of specific frequencies is virtually mandatory, especially if narrowband systems are allowed.)

Thus, almost any technology could be a candidate for PCS deployment, but they would have different economic and operational constraints. For example, although most existing narrowband systems which are candidates for PCS in Europe (eg, CT2, CT3, DECT, GSM, DCS1800, etc) are neither able to share very effectively with OFS nor are particularly spectrally efficient, they need not be eliminated. The sharing rules and interference definitions to be established for PCS may simply limit such systems to much lower power levels, larger exclusion zones before triggering mandatory negotiations for relocating OFS incumbents, fewer total channels, much closer positioning of base stations, and higher infrastructure costs. These systems' higher infrastructure costs, smaller cells, and lower capacity coupled with the added costs of higher front end expenditures for relocating incumbent OFS users will presumably have to be passed on to their PCS customers. A PCS system which can coexist much closer with the incumbent OFS users without triggering mandatory relocation negotiations would be permitted to use higher powers, larger cells, and initiate service earlier, thereby lowering infrastructure costs and offering more capacity. These lower costs would be passed on to the PCS consumers.

Thus the market will reward efficient sharing technologies provided the Commission establishes sharing rules and interference criteria which allows PCS providers to capitalize on truly innovative, efficient, sharing technologies.

In meetings with the Utilities Telecommunications Council (UTC) and as a member of various standards committees and industry groups concerned with the development of PCS, Omnipoint has consistently taken the position that no OFS incumbents should be put on a "forced march" as one OFS lobbyist described their fear. We believe that the PCS entrants should not interfere, and if the potential for interference, as defined by the exclusion zone rules to be established as part of the PCS proceedings, indicates that a PCS operator could cause interference, that PCS operator must first negotiate with the OFS incumbent to remove or otherwise compensate for the potential interference. In the event such negotiations are unable to resolve the issues within a specified period, either party may insist that as a condition of commencing PCS transmission in that exclusion zone, the OFS incumbent be relocated to equally reliable, equal capacity, alternative spectrum or communication means (eg, fiber optic cable, satellite, etc.) at no cost to the incumbent.

There would clearly also have to be rules defining what equally reliable spectrum means, minimum and maximum time frames for relocating and having in operation the alternative link, periods of redundancy provided by the original link until the transition was proven, and a means for arbitrating disputes.

Negotiated settlements could no doubt allow many OFS links to remain in the band if they chose to be compensated rather than moved. The PCS operator will clearly make the economic tradeoff between the cost of a relocation and the cost of the negotiated settlement. Coupled with the PCS operators ability to choose PCS technologies that have different exclusion zones, the free market will make many of the decisions that would otherwise require massive regulations.

Although this process would provide solutions for many situations, there would also have to be limits on what was negotiable. Critical communications links whether for public safety, utility load management, pipeline monitoring, railroad switching, etc should not be allowed to be negotiated away, especially not on any dynamic channel sharing scheme. One can never tradeoff the value of a critical communication against the willingness of consumers to pay for a call to check on what groceries they should buy on their way home from work.

For this sort of negotiated relocation to be feasible, several other sorts of procedures should be put in place. The following ideas are suggestions which need refinement but outline the basic parameters.

There will be concerns not only over what spectrum the incumbents will be moved to, but also with respect to what order they will be moved. Ironically, it may be the last ones to be moved rather than the first ones to be moved that will complain the loudest. One can not just say there are X MHz of spectrum in a higher band (for example 6GHz). The specific geographic pattern of the incumbent 6GHz

links, coupled with the geographic needs of the 2GHz links, as well as the need to plan for growth among both constituencies means that the optimal pattern of relocation should be planned as a totality for a given geographic area. If it is not planned as a whole, the first 2GHz links to be moved will get the "best" available frequencies without considering the impact on future 2GHz links which will have to be moved later. Some specific suggestions are:

- 1) To prevent a suboptimal frequency allocation of the higher bands, the Commission should empanel some entity to perform the equivalent of an "RF environmental impact" study for each MSA or region. The obvious candidates for assuming this responsibility are the PCS operators or entities which receive licenses for the largest blocks of spectrum in that area. As part of obtaining a license, these PCS operators could be required to perform the optimizing analysis for the entire frequency bands under consideration, even if that includes analyzing frequencies not licensed to them.

- 2) We suggest the Commission give strong consideration to creating a "Critical Needs Band" within the existing 2GHz allocation for relocation of OFS incumbents who truly cannot be moved to higher frequencies or alternative media. By establishing a portion of the band for the critical needs of incumbents, but placing stringent requirements for its use, the Commission can facilitate the entire relocation process. For example, if one or two pairs of existing 10MHz channels were set aside for critical OFS needs, but rechannelized into narrower allocations such as 500KHz to 1MHz, then up to 20 pairs could be assigned for links which truly need the

characteristics of 2GHz. These new links would be required to use the highest capacity equipment available with tight filters, high quality antennas, etc.

If this were to be coupled with the requirement for an "RF environmental impact study" as discussed above, then all the incumbents could be given an equal opportunity to identify precisely how many of their subchannels were really critical and required 2GHz. There are a myriad of ways to create incentives as well as checks and balances against abuse.

3) The Commission should specify a trial period -- perhaps 5 years -- to see if negotiated settlements work, rather than permanently grandfathering all the incumbents or specifying a date certain for going to secondary status. The Commission should defer judgement and reserve the right to review how well the process is working and reserve the right to require different policies in the future. It is a dangerous precedent to permanently grandfather any class of spectrum users.

4) Perhaps most importantly from a practical perspective, the PCS licensees should be given as much "flexible spectrum" as possible so that they have multiple parties with whom to negotiate for coexistence in any given geographic area. Without true negotiating flexibility, allowing recalcitrant incumbents primary or coprimary status will result in protracted litigation or arbitration before a service can be deployed. True negotiating strength can only be provided by allowing a PCS licensee the ability to negotiate with a different incumbent if one incumbent refuses to be reasonable.

In our pioneers preference we showed the flexibility of the Omnipoint system with respect to frequency coordination and regulatory allocation choices. Our fundamental point with respect to this issue was that a PCS system which could operate in any 10MHz contiguous frequency would have much greater chance of being deployed provided the rules allowed the use of "flexible spectrum". We did not specify how much flexible spectrum was necessary nor did we suggest that this flexibility should be permanent. We are not suggesting that PCS operators be allowed to use up all of the frequencies. Rather, without some initial flexibility they will not be able to truly negotiate to obtain stable frequency allocations through negotiated relocations. We believe ultimately each PCS operator will need 30MHz to achieve the promise of a mass market. Initially they might be allowed 50 or 60 MHz of flexible spectrum which would be reduced to a specific 30 MHz.

Perhaps in return for performing the "RF environmental impact study" and paying to create the "Critical Needs Band" the PCS licensees would be given 5 years of flexible spectrum choices. For example they could chose from among five or six specific 10 MHz channels to attempt to operate or negotiate in any cell. At the end of five years they would have to settle in a specific set of limited frequencies. Also by the end of 5 years the OFS incumbents would have to have negotiated settlements for relocation terms and conditions, or lose their rights to channels in the "Critical Needs Bands".

Obviously, there are many permutations on these ideas. The fundamental point is that a system with the flexibility of Omnipoint's

as described in our Pioneers Preference application will allow for maximum regulatory and negotiating flexibility.

II. Service Definitions and Spread Spectrum Technology Solutions

Omnipoint's Spread Spectrum System Is Radically Different From Any Other Proposed Spread Spectrum System

Although we tried to summarize in our Pioneers Preference the main differences between our spread spectrum approach and that of others, apparently at least one commenter --QualComm-- did not grasp how significant the differences are. To appreciate how fundamentally different Omnipoint's spread spectrum approach is, we need to first reconsider the basic architecture of CDMA only systems such as QualComm's.

The basic goal of the QualComm approach, as well as that of other CDMA only systems, is that capacity gains relative to FDMA and TDMA systems can be achieved through the ability to reuse the same frequencies in an N=1 reuse pattern. This is to be achieved by employing highly orthogonal codes, sophisticated adjustable power controls, and rapid soft handoff. Qualcomm also employs variable rate vocoding, 8Kbps peak speech rates, and cell sectorization to assist in minimizing the system's limiting factor, ie, interference.

We believe Qualcomm deserves significant credit for its achievements to date, and we wish them luck in overcoming their remaining hurdles, but they must recognize that theirs is not the only approach to capitalizing on the potential for spectrum spreading and coding innovations.

Both the strength and the weakness of a CDMA-only approach, lies in the method for achieving the $N=1$ reuse pattern. We can call these approaches "the precise adjustable power control CDMA approach."

The classic problem with direct sequence systems is the infamous near/far problem. In reality, the problem may or may not have to do with distance. The problem is how to distinguish users when the power levels received at a CDMA base station from multiple remote transmitters on the same frequency can vary enormously. Relative differences of 60 - 80db in received signal strength from different users are common due to obstructions, multipath fading, etc. Codes, no matter how orthogonal, can only provide a limited amount of user separation -- perhaps 18-21db in Qualcomm's system -- in a typical multipath channel. Further, this code separation is used up as more and more users are added to the system. To obtain the capacity gains, the signals must arrive at the base stations within 1-2db of each other. The classic solution is to use closed loop power control (ie, instructions from the base to the remote) to adjust the transmit powers of the remotes so that their signals all arrive within the tight tolerances required. In the near/far condition, the base station instructs the farther remotes to turn up their power while instructing the nearer remotes to turn down their power.

Achieving this within a cell or a cell sector where all the remotes are under the control of a single base station is fairly complex, but the real dilemma is dealing with the remotes on the same frequency but not under the control of the same base station (i.e. the

remotes in the facing cell sectors). Solving this problem is required in order to achieve the $N=1$ reuse scheme and derive the capacity and soft handoff benefits of CDMA-only systems.

The problem can be envisioned by picturing the intersection or overlaps of two or three cells or cell sectors. Each base station sees the interference from the remotes in all the cell sectors but only has control over the power levels of those within its sector. If different remotes from each sector are in the overlapping area and they both go by the same side of a wall, one base station is telling its remote to turn up its power and the other base station is seeing a major rise in interference. The solution to the problem in precision adjustable power, CDMA-only systems is rapid, soft handoff so that each remote is always under the control of the base station which can hear it the strongest.

And in that solution is the limitation of this precision adjustable power control CDMA approach.

It becomes immediately obvious that for this precision adjustable power control CDMA approach to achieve its capacity gains or to even work at all in an $N=1$ cell structure requires 1) that every base station or cell site be under the control of the same operator, and 2) that an entirely new switching architecture be developed.

Switches today are not designed to handle the fact that for a single user both inbound and outbound data traffic could be directed through

multiple base stations and switched between them on potentially a packet by packet basis during the call.

The ramifications of these two facts are profound for using a precision adjustable power control CDMA approach for PCS:

1) Qualcomm type systems must not only await the development of special switches for large networks but more importantly their precision adjustable power control CDMA approach means that their base stations cannot be connected directly to the public switched telephone network or any other installed base switching architecture such as PBXes. In essence, their system requires an independent cellular service type architecture approach to PCS rather than being able to leverage existing infrastructures.

2) In-building wireless systems using a precision adjustable power control CDMA approach cannot be independently owned and operated by different companies in proximity to each other using the same frequencies. Two independently controlled systems across the hall from each other in a multi-tenant office complex would jam one another with an $N=1$ reuse pattern. Without the $N=1$ reuse pattern, the Qualcomm system's capacity gains evaporate.

3) Even if the $N=1$ reuse pattern is sacrificed to allow independent ownership of base stations it is not clear what reuse pattern could be achieved for microcells so sensitive to small perturbations in power levels. Because these system must maintain received power levels within such tight tolerances (1-2db) to achieve reasonable capacity within a cell, any independent system relatively nearby on the same frequency can cause significant interference. As

our earlier experimental reports showed, the variations in propagation path loss are particularly significant for in-building wireless systems. As 60-80db differences between independent systems occur, any systems on the same frequency even fairly far apart can still jam one another.

4) Multipath induced frequency selective fading may also cause self jamming since this precision adjustable power control CDMA approach uses a control system employing open loop as well as a closed loop feedback to set the power levels of the remotes. The open loop uses the received signal strength from the base as a fast indicator of where to set the remote's transmit power level. As Qualcomm has stated in its literature to the T1P1 Committee

"If a fast power control method were not used, other users could experience a significant short term degradation in performance until the slower closed loop power control reduces the wireless handset's transmitted power to an acceptable level."

The problem is that the received signal is separated by 45MHz from the transmit signal in the cellular bands and is proposed to be separated by 80MHz in the 2GHz band. Coupled with the fact that the signal is only 1.25MHz wide, the frequency selective fades will be completely independent from the receive and transmit frequencies. Using received signal strength as an indicator for transmit power in severe fading environments is as likely to provide disinformation as information. Any resulting error in transmit power has the potential for causing interference to the entire system.

4) Increases in interference translate into significant reductions in capacity for precision adjustable power control CDMA

systems. On a fully loaded cell, a single interferer 3db higher reduces the cells' capacity by roughly 50%. This 50% reduction on a fully loaded cell appears to either mean all users lose threshold for communications or half the users must be immediately dropped.

The above comments on precision adjustable power control CDMA approaches are not meant as criticisms but rather to show how different PCS service concepts can require different technological approaches.

Omnipoint's system was designed to allow independent ownership and operation of base stations and to allow direct interconnection to existing switching architectures. It was also designed to coexist with OFS users.

Although there are many differences between our spread spectrum system and that of others, perhaps the most important difference is that we do not rely solely on codes and precision adjustable power controls to separate users. We primarily use a complex hybrid of codes, frequency offsets, and time to separate users.

Through the use of a proprietary coding scheme we are able to drive the data rate per frequency channel to extremely high rates and to then use time to separate users within a cell. We then use frequency offsets and codes to separate cells. Unlike traditional TDMA systems we are able to use thousands of time slots per second if we choose. By employing time to separate transmissions, we completely eliminate the classic near/far problem. Time separation is the ultimate interference avoidance mechanism. Time separation also allows

for make before break handoffs because each user's handset can monitor the other time slots besides the ones it is using for communications and establish a second link on another time slot on the same or another base station before letting go of its original time slot.

Omnipoint's system does not require precision adjustable power controls and continuous soft handoff to maintain capacity and could in fact operate even without power controls, an impossibility with CDMA only systems. The system also can not be brought down by a single handset either operating within the network or in an adjacent independent network. In fact, unless the system is completely loaded, a single interfering handset will have almost no impact. Even in the fully loaded case a single interfering handset can only affect one user not the entire system. As a consequence, the base stations can be independently operated, which is a requirement for serving the private premises market.

Omnipoint's system does not require new switching technology. In fact, in conjunction with Ameritech's leadership in this area, Omnipoint is developing an interface to ISDN based switches that could lead to existing switches performing most, if not all, of the mobility management functions normally thought to require offloading to separate switching equipment. The same applies to use of our system with PBXes and Centrex.

Omnipoint is using spread spectrum to achieve substantial capacity gains by employing it to overcome the effects of delay spread and frequency selective fading to substantially raise the achievable

data rates within a given bandwidth and cell size relative to traditional narrowband systems without requiring complex, power consumptive, adaptive equalizers or precision adjustable power controls.

Simply put our implementation of spread spectrum simultaneously achieves capacity gains and sharing capabilities with OFS while reducing system complexity.

III. Defining Interference as the Key to Introducing PCS

Defining The Meaning of "Primary and Co-Primary" For Mixed Use of the OFS Band Will Determine Whether Sharing Is Possible

Regardless of the PCS system proposed by a prospective operator, one of the single most important issues to be resolved regarding the reallocation of the Emerging Technologies band is the definition of co-primary and primary.

Unless band clearing is used, (which no one wants) then a) defining interference and coexistence between OFS and PCS, and b) establishing the process for determining compliance will become the keys to sharing.

Much of Omnipoint's contribution to facilitating the emergence of new technologies that can truly share spectrum in these bands stems from our work at actually measuring how various RF modulation and multiplexing schemes affect real microwave facilities.

We obtained actual microwave equipment currently in use and we built very careful test set ups to calibrate the effect of various potential types of PCS transmitters on the microwave receivers, including:

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100 KHz systems similar to CT2
200 KHz systems similar to GSM and DCS1800
500 KHz systems similar to those proposed by BellCore
1.25-1.8MHz systems similar to some CDMA proposals and DECT

5MHz and
10MHz

systems reflecting our own hybrid approach which incorporates CDMA, TDMA, and FDMA with frequency agility.

We had also analyzed wider CDMA systems such as those proposed by PCN America (originally 48MHz duplexed into 96MHz, and now 40MHz time division duplexed) as well as our own 13-25MHz systems. However, we quickly confirmed three years ago our initial premise that such wideband systems were unrealistic for use in the 1850-1990MHz band. While we encourage others, if they choose, to attempt to develop adjustable notch filters and other measures reducing broadband interference, we confined our development to PCS architectures using 10MHz or less per frequency channel. Simply put, this decision was based on 1) the fact that the geographic pattern of actual microwave links in most major cities would mean that in many if not most cells any signal wider than 10MHz would be in the beam path of at least one microwave receiver no matter how much frequency avoidance was employed, thus requiring relocation rather than sharing; (2) the inevitable fact that the definition of sharing and interference will result in case by case determinations or negotiations that involve 10MHz channels since 95% of the users in this band are licensed in 10MHz channels now; and 3) our belief that the Emerging Technologies band should be reallocated for multiple, portable, RF uses and competitive service operators, whereas PCS systems that required

greater than 10MHz channelization could inhibit regulatory flexibility. Thus the first step to determining the sharing abilities of any PCS system is to analyze how real microwave receivers react in the presence of different types of PCS interference.

Summary of Analysis:

The Size of Exclusion Zones Varies Primarily Due to Differences In:

- Width of the PCS System's Frequency Channels.
- Propagation Assumptions
- Cumulative PCS Interference Per Cell

Real World Interference To OFS From PCS Systems
Increases Dramatically as Bandwidth Decreases From 10MHz

Since 83% of all OFS links use analog microwave systems, we focused our initial analysis on these receivers. As the attached experimental results prove, narrowband systems will cause significantly greater interference to these OFS users than Omnipoint's 10MHz system at the same power levels. Given that interference to a microwave receiver continues to be defined by the TSB10E standard as a 1db rise in the receiver's noise threshold, then a narrowband 100KHz PCS system will require exclusion zones which are 100 times larger outside the beam path than Omnipoint's 10MHz system given the same power levels and propagation assumptions.

Propagation Assumptions Dominate the
Determination of Exclusion Zone Sizes Around an OFS Receiver

Hata Models are Inappropriate for Determining Interference.

It Is Not the Average Path Loss but the Path Loss of the Worst Cases
that Determine Interference and Exclusion Zones

Almost all exclusion zone analysis done to date assumes Hata propagation model characteristics prevail for estimating path loss from a PCS transmitter to an OFS receiver. As detailed in our Pioneer's Preference, Hata models are not appropriate for estimating interference to OFS receivers. Hata models were not designed for this purpose, rather they were designed for cell site planning for filling in coverage.

The problem with using Hata Models for interference analysis to OFS receivers is that they are derived from regressions, which in essence result in using only average path losses. However, the variance around the average at any given location is enormous. From an interference perspective it is not just the average which is relevant, it is the worst case.

To put this in graphic relief, consider that in our field tests we measured signal strengths at 12 miles from a microwave tower which were 50db stronger than predicted by Hata Urban. One handset at this location is the equivalent of 100,000 handsets assuming the Hata average.

In fact, the variance around the Hata models assumes that at least 2.5% of the locations will always have power levels at least 20 db or 100 times greater than the derived regression average.

The difference in the size of an exclusion zone derived using the most conservative Hata model -- Large City, Urban -- versus Free Space, is roughly 2000 fold.

The relevance of this for designing a PCS system that can coexist with OFS users is obvious when coupled with the conclusions regarding narrowband systems and the cumulative interference of traditional CDMA systems.

A single narrowband PCS handset, for example using 200MHz frequency channels such as GSM and using 100mW of power, could cause interference to an analog OFS tower even 90 degrees offset to its beampath from 35 miles away if it obtained free space propagation.

Near free space loss conditions are not necessarily a rare event. In our field tests, it was very easy to identify numerous locations where near free space propagation was measured within the first several miles. Even beyond 10 miles, up to 10% of our measurements resulted in propagation coefficients within roughly 10db of free space. Nor were these measurements ephemeral events. In our field tests we measured actual degradation to an OFS receiver from different types of PCS transmitters at various locations and distances. At 14 miles away and 30 degrees outside the beampath we could degrade the OFS by 1db using just 2 to 44mW from a single narrowband signal. On one embankment 6.3 miles away and 45 degrees outside the beampath, there were five locations within 100 feet of each other where a single narrowband transmitter interfered with the OFS using 10 mW or less. At each of these locations, the PCS transmitter would continue to interfere for as long as the transmitter was left on.

We are currently developing more representative propagation path loss models based on Longley-Rice area models (TIPEM) to evaluate

the effects of large numbers of users. Even under the more realistic assumption of using a worst case propagation occurring somewhere between Free Space and Hata Suburban, single narrowband handsets will cause interference from many miles away.

Cumulative Interference Per Cell Varies
Dramatically Depending on the PCS Technology Employed

In all other known PCS systems other than Omnipoint's, the aggregate interference per cell rises at least proportionately with the number of users. Even traditional CDMA systems, though spreading their signals, cumulatively add interference on to the same frequency band as the number of users in a cell or cell sector rises. For example, in larger cells, 60 users at an average of 100mW will produce 6 Watts of interference over that frequency band.

In contrast, an entire loaded cell using Omnipoint's 10MHz system with all channels active could operate within 5 miles of an OFS tower under the same assumptions using worst case Free Space loss propagation, and closer to 2 miles under more realistic worst case conditions. This is also precisely what our field experiments have demonstrated as well.

Using the Omnipoint system, at no location 2 miles or further from the OFS receiver (and outside the beam-path) could we raise the noise threshold 1db on any channel while transmitting at 100mW. In fact, out of all the measurements 2 miles or further away, in only one case could we raise the noise floor by 1db even using the maximum transmit power of 500mW.

The Definition of Co-Existence Must
Recognize the Differences in PCS Systems

We strongly doubt that the Commission has enough information to actually specify a modulation scheme, or that the Commission desires to set such standards. Conversely, we assume that the Commission will continue its role of setting criteria for determining interference. What we hope we have shown in our Pioneers Preference request and in our experimental report, is the need to use criteria which reflect the radical differences between different PCS approaches with respect to their ability to share with OFS users.

The PCS industry, the incumbent OFS users, and the Commission are well aware of the fact that on average, roughly 75% of the OFS links in the major MSAs are 25 miles or further from the city centers. Through careful frequency selection on a cell by cell basis, the beampaths of most of these can be avoided within that 25 mile circumference. After that, the ability to share geographically outside the beampaths, is a function of the PCS system design.

As discussed above, all proposed PCS systems should have the right to negotiate co-existence. But the trigger for forcing negotiation is whether the technology selected by the PCS operator is being used outside that technology's defined exclusion zone. If a narrowband PCS system can interfere from 25 miles away then it will have to negotiate with virtually all the incumbent OFS users in that city in a given frequency before it can put even the first PCS cell into operation. With Omnipoint's system, a PCS provider could initiate operations in most cities within the first 1200 square miles before requiring negotiations.

Recognition of Other Pioneering Efforts

While we have tried to read all of the Pioneers Preference Requests, we cannot say that we were able to give all of them the same attention given the breathtaking pace and the numerous deadlines of the PCS and Pioneers Preference proceedings.

We noted in our Comments to the May 4, 1992 Pioneers Preference filings that we thought the Commission had a unique opportunity to encourage both innovation and cooperation by awarding multiple preferences in the PCS proceeding. We urged the Commission to avoid the damaging message it would convey to future entrepreneurs by awarding only one or two preferences or none at all. We suggested they should recognize multiple competing technologies as well as the efforts of competing service providers.

We believe that many parties have made significant contributions in many different ways, ranging from market research to innovative policy recommendations. Many of them have spent millions of dollars in ways which all of us have benefited. We are not lawyers nor able to ascertain the subtleties of the pioneers preference rules, but we hope they allow the flexibility to recognize many kinds of innovators that will otherwise probably be returned to the fate of the lottery process.

In particular with respect to common carrier telephony based pioneer preferences we urge the Commission to look carefully at the efforts of Bell Atlantic, Ameritech, the Pacific Telesis Companies, Westinghouse/Pertel, PCNA, Locate, and APC. The first three companies we have worked with and can give direct testimony to their significant

efforts. The latter four we have no business relationship with, but we have followed their efforts, frequently disagreed with them, but always admired their entrepreneurship and tenacity in pioneering the difficult PCS wilderness.

Bell Atlantic's and the Pacific Telesis Companies have already been recognized by others and we concur with those comments. Ameritech's efforts at providing careful definitions of PCS through scientific market research may have obscured their technical innovations in modifying the National ISDN-1 standard to allow mobility management from central switches.

Westinghouse/Pertel has the unique perspective of being both a major OFS incumbent as well as a pioneer in PCS. Their open attitude and efforts in testing all technologies to determine the best approach for deploying PCS is deserving of recognition.

PCNA's, Locate's, and APC's contributions are well known and voluminously documented. We disagree with some of their technology approaches but we recognize them as fellow pioneers.

1.0 Introduction

Responsible spectrum sharing with incumbent OFS microwave users requires a clear understanding of how these systems react to different types of interfering signals as a function of range, bandwidth and format. Depending on modulation format and bandwidth, OFS microwave receivers exhibit markedly different responses. In particular, OFS receivers are as much as 20 dB more susceptible to narrowband interference than Omnipoint's 10 MHz signals. As a consequence of this, narrowband systems will require large exclusion zones and have greater difficulty in sharing with incumbent OFS users. Required exclusion areas are likely to be up to 100 times larger for narrowband systems. Complicating the issue, propagation conditions into the victim OFS receiver are highly variable. The Hata⁶ propagation models used in most filings present an overly simplistic view of the interference potential from PCS. Based on field measurements taken in the 1962-1965 time frame by Okumura¹, the Hata models represent median propagation path loss in quasi smooth terrain. As such, they do not address the "rogue" handset problem. Compared with Hata, Large city Urban predictions, a single handset, located in a region where near free space propagation conditions prevail, can appear one hundred thousand times stronger to an OFS receiver. We have observed this situation in our field testing².

⁶M. Hata, *Empirical Formula for Propagation Loss in Land Mobile Radio Services*, IEEE Transactions on Vehicular Technology, August 1980

¹Y. Okumura, *Field Strength and its variability in UHF and VHF land-mobile radio services*, Tokyo Rev. Elec. Commun. Lab. vol.16, 1968. Reprinted in *Land-Mobile Communications Engineering*, IEEE Press, 1984

²Propagation results are contained in section 4.0 of this report.

2.0 Microwave Receiver Sensitivity to PCS Interference

Examining the principles of operation for FDM-FM receivers, we have concluded that narrowband interference is more damaging to OFS microwave receivers. Specifically, the narrowband FDM-FM modulation format used by 83% of all licensed users is more susceptible to narrowband interference effects because each baseband voice channel's spectral occupancy is concentrated in two, 3.1 kHz bands. A series of tests, both in the lab and in the field were undertaken to validate our theoretical models.

The principle of operation is essentially the same among all OFS analog FDM-FM equipment. Figure 2.0-1, taken from the operations manual, shows specifications for the Motorola Starpoint transmitter/receiver pair used in our testing. The equipment used for testing operates in the common carrier band at a 2178 MHz center frequency. We used a 96 channel model (P65 option) with a per channel RMS deviation of 47 kHz. Table 2.0-1, taken from the TSB10-E identifies an OFS receiver with identical parameters, except operating in the 2130-2150 MHz and 2180-2200 MHz POFS allocations. Of particular importance, the modulation index is small; around 0.25. These systems are in actuality using a narrowband FM signaling format, even though the bandwidths are large. Figure 2.0-2 provides a system block diagram of the transmitter and receiver.

2.1 Bench Test Results

In quantifying an OFS receiver's sensitivity to interference, both loaded and unloaded operation must be considered. Unloaded operation refers to situations where essentially none of the voice channels are in use while loaded operation considers the case where essentially all voice channels are in use. In the unloaded situation; the OFS receiver's

sensitivity is set mainly by noise Figure. As voice channels become active, intermodulation distortion becomes important in setting the apparent noise floor of the OFS receiver. This is because nonlinearities in the OFS Transmit/Receive process introduce intermodulation products between voice channels that map into other voice channels.

2.1.1 Test Procedure (Bench)

Figures 2.1.1-1a and 2.1.1-1b diagram the baseline bench test setup used. Referring to the first Figure; a Marconi noise generator and a Krohn-Hite programmable filter is used to simulate baseband voice channel loading in accordance with CCIR recommendations. Switchable narrowband bandstop filters at 14 kHz, 245 kHz, and 342 kHz center frequencies can notch out selected frequencies to simulate unused voice channels and observe intermodulation distortion. In unloaded testing, the noise generator is switched "off" so there is no input to the Motorola FM transmitter.

The Motorola Starpoint transmitter has a nominal output level of 1 Watt (+30 dBm). To simulate typical path loss, 90 dB of attenuation is inserted between the transmitter and receiver. This corresponds to a nominal fade margin of 22.5 dB; considerably less than most OFS systems³. In consequence, our interference studies are conservative in their estimates of how much power is needed to interfere with the OFS operator.

The Motorola Starpoint receiver used has been specially modified to include several monitoring functions in a Rx/Tx drawer test set. These modifications do not affect

³One study conducted by COMSEARCH, considering 107 links in the Houston area, found that the average fade margin is 54.4 dB.

receiver operations but allow monitoring receiver internals not normally output. Specifically, it allows us to determine whether or not the 607 kHz pilot tone is being received correctly.

The demodulated baseband FDM signal is then input into a Cushman, frequency selective level meter. Selecting a bandwidth of 3.1 kHz, this meter allows direct observation of the power level in any voice channel since the center frequency is tunable.

Interference signal input is also shown in Figure 2.1.1-1a. After 30 dB of amplification, the interfering source is passed through a -10 dB directional coupler into a Boonton 41-41 Power Head where it is envelope detected. A Boonton 42BD microwatt meter then gives a calibrated reading of the interference source power. The main feedthrough output of the directional coupler is input into the -20 dB port of another directional coupler to inject interference into the simulated OFS link.

Five test points are indicated in Figure 2.1.1-1a; TP1 through TP5. An HP 8595A Spectrum analyzer can be connected at each of these test points to obtain a picture of the composite spectrum.

One of the key objectives in our testing is to quantify the effects of different types of interference sources. Referring to Figure 2.1.1-1b, we have constructed a specialized item of test equipment; the Bob Dixon Box; to generate a variety of interfering sources. An HP-8018A serial data generator is set to generate length $2^{31}-1=2,147,483,647$ maximal

length (ML) pseudo random code⁴. An attached frequency counter monitors the serial bit rate generated.

Serial data from the HP 8018A is then filtered by one of three filters; a 10 MHz LPF, a 5 MHz LPF, or a Krohn-Hite programmable filter. The resultant is then mixed with an appropriate CW signal from the HP 8660C synthesizer to translate to RF. Depending on the selected filter bandwidths and serial data chipping rate, a wide variety of interference source signals can be provided. As an example, if the code generator is run at a high rate and a narrow filter is used, the output will be a quasi noise source with essentially Gaussian characteristics⁵. Slowing the chip rate, the output of the mixer takes on a BPSK, constant envelope characteristic, typical of many narrowband modulation formats and direct sequence spread spectrum signals. Figures 2.1.1-2a and b, measured at TP2, illustrate this effect.

In the first Figure, a nominal 1 MHz chipping rate signal is fed into a 50 kHz LPF⁶ and then translated to a 2,178,014,000 Hz center frequency to produce a noise like spectrum. In the second, the chipping rate is cut to 100 kHz while other settings remain constant. Note the slight residual $\sin x / x$ sidelobe present.

Figures 2.1.1-2c and 2.1.1-2d show spectrums of 0.2 MHz and 0.5 MHz bandwidth quasi noise interference source signals used in this study. Although they appear identical, they are not; the spectrum analyzer span (indicated in the lower right corner of the Figure) is different between the two Figures. Figures 2.1.1-e through g depict 1.25, 5.0 and 10.0

⁴An ML code was selected because it has a flat line spectrum, with equal power in each spectral line.

⁵By the central limit theorem, when the LPF "adds" together a large set of identical distributed random variables, the resultant is Gaussian.

⁶Implemented using two sections of the Krohn-Hite filter.

MHz bandwidth filtered BPSK interference source signals. The 5 and 10 MHz cases are representative of Omnipoint signals while the 1.25 MHz signal is representative of other proposed CDMA systems..

We also tested using the HP 8660C's FM modulation section. Figure 2.1.1-2h show the spectrum of the 100 kHz bandwidth FM signal used in our tests. The baseband modulating waveform was a 1kHz sine wave and the modulation index was adjusted to give the desired bandwidth.

2.1.2 Unloaded Interference Sensitivity (Bench)

In the unloaded test configuration; the Marconi noise generator is turned *off* resulting in zero input to the Motorola Starpoint transmitter. Figure 2.1.2-1 depicts the transmitted signal spectrum, measured at TP3. Nominal FDM-FM signal power at this point is -20 dBm. The spectrum consists of two main components; the carrier and the pilot channel, located at a 607 kHz offset. The pilot channel is generated in the transmitter by adding a 607 kHz sine wave to the baseband signal. Since its frequency is above the top, 400 kHz voice channel, it does not interfere with voice channel information. The pilot signal serves several purposes; it is used to set gain on the baseband signal; it provides link quality assessment; and, it serves as a BFO reference for the SSB-FDM signal⁷.

Figure 2.1.2-2, measured at TP4, shows the output baseband signal spectrum under unloaded conditions. As expected, with pre emphasis/de emphasis turned off, the noise

⁷Because the baseband FDM signal is a series of SSB signals, slight frequency offsets in the SSB demodulation process result in the "Donald Duck" syndrome. The pilot signal provides a reference signal to measure any frequency shifts introduced by the FM transmitter/receiver pair.

level rises with frequency. The spiky signals in the lower portion of the spectrum are of undetermined origin but are generated within the receiver itself. Although they appear large, they are in actuality quite small in comparison with an active voice signal⁸.

In Figure 2.1.2-3a, we have added in a 100 kbps, filtered BPSK⁹ signal at a frequency of 2178.2 MHz; 200 kHz above the Motorola Starpoint's nominal center frequency. The interfering source's power level is -80 dBm, referenced to the Starpoint receiver's input. The resultant baseband signal spectrum is shown in Figure 2.1.2-3b. Note how the power bump has formed at an offset of 200 kHz. 3.1 kHz FDM voice channels operating in the neighborhood of this bump would experience significantly higher interference compared with voice channels at far removed frequencies.

Repeating the experiment except using a 10 MHz filtered BPSK signal¹⁰ typical of Omnipoint's system, we obtain the results of Figures 2.1.2-4a and b. Comparing Figure 2.1.2-4a with Figure 2.1.2-1 (no interference case) we see that the wideband Omnipoint signal appears much like an elevated noise floor going into the FM receiver except for the spur at a 200 kHz offset. This spur is due to LO leakage through the double balanced mixer in Bob Dixon's Box¹¹. In practice we can eliminate this leakage term using a proprietary technique but for test purposes we decided to leave it in since it makes a handy marker for the interfering source center frequency.

⁸See section 2.1.3 for examples of loaded voice circuits.

⁹See figure 2.1.1-2b in section 2.1.1

¹⁰The spectrum of the test signal is shown in figure 2.1.1-2g. In actual systems, the small sidelobes are eliminated using pulse shaping techniques not included in our test setup.

¹¹Diagrammed in figure 2.1.1-1b

Examining Figure 2.1.2-4b, we note that the baseband FDM signal does not exhibit the pronounced power bump seen in Figure 2.1.2-3b. In fact, comparing the two cases, we see that the power bump is 20 dB higher than corresponding frequencies for the Omnipoint spread spectrum signal. This is because the narrowband FM¹² demodulation process used in FDM-FM receivers is essentially a spectrum preserving process. A narrowband signal going into the FM discriminator will come out a narrowband signal. The spread spectrum signal spreads its energy over a wider range of frequencies, hence it has a low spectral density going into the FM discriminator. This low spectral density is preserved on output from the FM discriminator.

In Figures 2.1.2-5a and b, we consider an intermediate case, using the 1.25 MHz filtered BPSK signal¹³ as an interfering source. This is representative of the direct sequence QPSK CDMA signals proposed by several companies in their pioneers preference filings. In the RF spectrum plot, we note some spectrum rolloff, but, because the span is only 2 MHz we don't observe the full spectrum of the interfering signal. Examining the baseband spectrum plot (Figure 2.1.2-5b), we see results that at first glance, appear very similar to the results obtained with a 10 MHz spreading bandwidth. *They are not!* If we superimpose the two plots, the Omnipoint signal results in a factor of 9 dB less interference because it has a 9 dB lower spectral density.

Up to this point we have been examining spectral plots to show how the interfering source's bandwidth affects the baseband signal. In order to make quantitative statements about how much interfering power can be tolerated as a function of bandwidth, we use the Cushman frequency selective level meter to measure power in a 3.1 kHz voice

¹²Modulation index of 0.25

¹³Depicted in figure 2.1.1-2a

channel bandwidth. FDM voice channels centered at 14 kHz, 245 kHz, and, 342 kHz were taken as representative and designated Low, Middle, and High respectively. We then introduced each of the eight types of interference identified in Figures 2.1.1-2a through h and measured the required interference power necessary to cause 1 dB, 3 dB, 6 dB and 10 dB of degradation in the selected voice channel. In each case, the interferer was centered on the target voice channel's baseband FDM frequency offset. As an example, if the Medium channel (245 kHz) voice channel is to be targeted, the interfering source was tuned to a center frequency of $2178 \text{ MHz} + 245 \text{ kHz} = 2178.245 \text{ MHz}$. Wide band interference sources were moved over an additional 30 kHz to avoid biasing the results with mixer LO leakage.

Table 2.1.2-1 summarizes the results of this study. For each interference type, we first measure the base channel noise power with no interference present. Then, we gradually increase interference power until the voice channel power increases by 1 dB as measured by the appropriately tuned Cushman meter. We then note the required interference power, as measured by the Boonton microwattmeter and reference it to the FM receiver antenna post (subtract 60 dB from the measured value). This procedure is then repeated for 3 dB voice channel degradation etc.

In examining these results and the plotted results seen in Figure 2.1.2-6, we again confirm our expectation that FDM-FM systems are more susceptible to narrowband interference. As expected, the relative susceptibility goes as the ratio of the bandwidths. Comparing results for a 100 kHz interfering source with those for a 10 MHz source, we see that the FDM-FM receiver is

$$10 \log (10 \text{ MHz}/100\text{kHz}) = 20 \text{ dB}$$

more vulnerable to the narrowband interferer. With regards to spectrum sharing, the implications of this are enormous. For a given power level, we can be a factor of ten times closer to an OFS receiver before we cause the same level of interference. This means that our exclusion zones¹⁴ will be 100 times smaller in terms of area.

2.1.3 Loaded Interference Sensitivity (Bench)

In assessing the potential for interfering with FDM-FM OFS links, we also need to consider the loaded case where the link is carrying voice traffic. Rather than try and find 96 telephones and hook them up to the transmitter with 96 people on the line, the CCIR recommends using a noise source to simulate voice traffic. In the test setup of Figure 2.1.1-12, the Marconi noise generator and Krohn-Hite filter are used to generate simulated voice traffic.

Figure 2.1.3-1a shows the resultant simulated traffic power spectrum measured at TP1. Feeding this signal into the FM transmitter results in the RF signal spectrum shown in Figure 2.1.3-1b. Note how the pilot and carrier signals are no longer visible. They are still there except with significantly lower amplitudes, energy is being "robbed" to carry the voice traffic. After demodulation in the FM receiver, we obtain the signal spectrum shown in Figure 2.1.3-1c, measured at TP4. It looks about the same as the input baseband signal measured at TP1.

¹⁴Regions where inband PCS operation is prohibited since it will violate OFS interference criteria.

In order to measure the effects of interference on the FM receiver, we notch out selected portions of the input baseband spectrum as shown in Figure 2.1.3-2a. Here, the bandstop notch filters shown as part of the Marconi noise generator are switched in to simulate empty voice channels. This signal, measured at TP1, is then fed into the FM transmitter/receiver chain. After demodulation by the FM receiver, we obtain the results of Figure 2.1.3-2b, measured at TP4. Of particular importance, note how the notch depth has been filled in. This is because of intermodulation distortion inherent to the FM radio chain.

Nonlinearities in the Transmitter/Receiver chain cause elements of the baseband signal to mix together, producing new and undesired frequencies. In a sense, the FDM-FM system is self jamming itself.

In Figure 2.1.3-3a, we have added in a -80 dBm (referenced to the receiver port), 100 kbps filtered BPSK interfering source centered at 2178.27 MHz. As expected, the notch filled in with interference. Comparing with Figure 2.1.3-2b¹⁵, the 245 kHz notch depth has degraded from 35.77 dB to 11.93 dB. Voice channels operating in the neighborhood of 245 kHz have had SNR degraded by $35.77 - 11.93 = 23.84$ dB.

Figure 2.1.3-3b repeats the experiment with an Omnipoint 10 MHz signal. Notch depth improves 11.5 dB, demonstrating the reduced interference potential of the Omnipoint waveform. In Figure 2.1.3-3c, we consider the intermediate case of a 1.25 MHz filtered BPSK interfering source. Notch depth degrades by about 6 dB. Since the lab results are based on rather low FDM-FM received levels, we expect that redoing the series for a

¹⁵This figure was measured about three hours earlier than figure 2.1.3-3a through c. Apparently the Krohn-Hite filter had drifted over this interval, hence the shift in level and shape.

higher FDM-FM signal level, we will again see results more along the lines of the unloaded case.

2.1.4 Bench Test Conclusions

Our bench testing has conclusively shown that under both unloaded and loaded conditions, FDM-FM receivers are significantly more susceptible to narrowband interference as we had claimed in our pioneers preference filing. Specifically, we have demonstrated that: for a given power level, FDM-FM receivers are 100 times more susceptible to 100 kHz narrowband interference than 10 MHz Omnipoint type signals in the unloaded case. As a consequence of this, we expect that our exclusion zones will be 100 times smaller in terms of area than comparable narrowband systems.

Figure 2.1.4-1, taken from our filing, reiterates this fact, showing required exclusion radius as a function of transmit EIRP for both narrowband and wideband signaling formats. In all cases, free space propagation is assumed to provide an upper bound on required exclusion radius.

2.2 Field Test Results (Interference)

As part of our testing, we put together a mobile van test setup to experiment with jamming an active point to point microwave link. The link was operating at normal power levels with a fade margin of 35 dB.

Referring to Figure 2.2-1a, the microwave link test setup uses essentially the same equipment as in the bench test except now, actual dish antennas are used. The test site¹⁶ transmits either unloaded or loaded FDM-FM signals as described in section 2.1. An additional 10 dB of attenuation can be switched in to model fading effects.

The victim FDM-FM receiver is located in downtown Pueblo Colorado¹⁷ on top of a 130' tall building. As described in section 2.1, a Cushman Frequency Selective Level meter is used to measure interference effects.

The mobile van unit carried the complement of equipment indicated in Figures 2.2-1b and c. This is fundamentally the same equipment used in the lab except with the interference source driving a linear power amplifier¹⁸ and a discone antenna located 13' AGL. The Boonton power meter taps into the transmission path through a net 30 dB of attenuation to provide a calibrated measure of the transmitted interference power.

When using the Bob Dixon Box (BDB), maximum EIRP from the van is around 500 mW because of insertion losses associated with the double balanced mixer. When using a CW interfering source from the HP 8660 synthesizer, the BDB is bypassed; maximum EIRP increases to 2.4 Watts.

A continuous wave (CW) signal is indicative of a homogeneous 100kHz signal (a string of "1's" or "0's"), as is common in some systems during an "idle" state. Table 2.2-1aa (Unloaded Filed Test Results (Interference)) clearly indicates that a CW signal is very

¹⁶Tower base located at 35 44' 45.74"N, 104 50' 34.69" W, Elevation 6925' AMSL. Antenna height of 55' AGL.

¹⁷Tower base located at 38 17' 21.33"N, 104 35' 46.65" W, Elevation 4742.7' AMSL. Antenna height of 144' AGL.

¹⁸Nominal 1 Watt maximum power output.

likely to interfere with an OFS user even when the CW source is not in the main beam. At nearly 14 miles, 1.6mW of CW signal 30° outside of the mainbeam caused the maximum allowable TSB10-E degradation, i.e. 1dB. Similarly, one seventh of a milliwatt of CW 7.5 miles away and 34° offset from the main beam causes 1 dB of degradation.

Personnel at the van and the test sites were linked together via cellular phone conference calls permitting a test procedure similar to that used in the lab. At each test site, we performed a series of interference tests using the narrowband, 100 kbps BPSK signal and the 10 MHz wideband spread spectrum signal. In general the results agreed with our bench tests; the narrowband signal proved approximately 20 dB more damaging for a given power level in the unloaded case and 10 to 15 dB more damaging in the loaded case. Required exclusion zones will be significantly larger for narrowband equipment.

Tables 2.2-1a and b show field test results for unloaded and loaded cases respectively. In several instances, we did not have sufficient interference source transmit power to achieve the desired interference level into the FDM-FM victim receiver. These cases are noted with an "n" in the tables. Blanks indicate tests not performed.

In these tables, the first column shows interference source range from the Pueblo FDM-FM receiving station. The second column indicates how many degrees off boresight the interfering source is, measured in a clockwise direction. Zero degrees is the mainbeam direction where the dish antenna is pointed. The interference type is then indicated. Quiescent baseband noise level (no interference) is measured prior to each interference test, providing a reference level for measuring voice channel SNR degradation.

We also experimented with the switchable 10 dB attenuator at the transmit site to simulate moderate fading conditions.

3.0 Field Test Results (Propagation)

In reading the various filings and propagation test reports, we have come to the conclusion that the use of Hata propagation models may be unrealistic for establishing exclusion zones. This is true in the context of mobile users since a single handset can potentially obtain near free space propagation to that microwave tower and jam it. In our opinion, several reports submitted to the FCC paint overly optimistic results on sharing by using Hata Urban models to derive exclusion ranges.

In obtaining some propagation data of our own, we mounted a discone antenna on the Pueblo test site microwave antenna at a height of 138 feet above ground level (AGL) and transmitted at 2178 MHz with an EIRP of 32 dBm. On the van, we mounted two discone antennas, one on the roof at 6' AGL and another on a mast at 13' AGL. We equipped the van with a Trimble GPS navigation unit to measure position. We then drove around in the Pueblo area measuring signal received signal strength.

Results from this testing are shown in Figures 3.0-1a through c. In each of these Figures, expected results for the various¹⁹ Hata models are included as well as the free space prediction. In particular, we note that near free space propagation can be obtained at a range of 12 miles. Signal levels from a PCS handset at this location into the microwave tower would be 100,000 times stronger than predicted by Hata Urban models. A single handset at this location would be equivalent to 100,000 handsets at an average location. Rogue handsets present a significant threat to the incumbent OFS user unless properly accounted for in the propagation modeling.

¹⁹Large City models with a base station height of 138' and a mobile antenna height of 6'.

Figures 3.0-2a and b²⁰ show that this is not just a pathological case; significant deviations from the Hata predictions are observed in both cases. This is in fact the main weakness in using the Hata median propagation loss formulas for developing path loss predictions; they only predict medians. In developing responsible criteria for sharing with incumbent OFS users, it is important to not gloss over this fact.

²⁰Taken from Motorola's July 24, 1991 filing with the FCC

4.0 Conclusions and Planned Additional Interference Testing

Bench testing with a representative FDM-FM receiver has conclusively shown that interference susceptibility is a function of interfering source bandwidth with narrowband formats doing the most damage. As a consequence of this, narrowband systems will require large exclusion zones and have greater difficulty in sharing with incumbent OFS users. Required exclusion areas are likely to be 100 times larger for narrowband systems. Outdoor interference testing indicated that the bench test results will hold in actual practice; we were able to interfere with the FDM-FM receiver at much longer ranges when using narrowband signals.

Digital radios are the other major type of equipment used by OFS users though they only constitute a small minority of systems. We have obtained the use of a Farzon-Harris digital radio link capable of supporting a DS2 data rate²¹ and plan to conduct another series of interference tests with this equipment. A BER degradation criteria along the lines of TSB10-E will be used to evaluate interference effects. We expect to see differences in susceptibility between narrowband and wideband cases based on published T/T²² criteria as a function of frequency.

Finally, we have measured propagation path losses as a function of range to a microwave tower and found that it is highly variable. Results are consistent with Motorola's published data on this topic. In some cases, the propagation path losses were 100,000 times smaller than predicted by the Hata Urban models used by some authors in their reports on spectrum sharing. Even in large cities, we expect that free space propagation

²¹6.176 MEPS or four times the T1 data rate of 1.544 MBPS.

²²Threshold to Interference

can prevail into a microwave tower if the handset is located in a rogue position (e.g. balcony, rooftop, etc.). Responsible sharing must address this problem. Omnipoint's approach has been to develop signaling formats that are inherently less damaging to OFS receivers and then assume very conservative propagation path loss models.

Channels	Per Channel RMS Deviation (Hz)	Average Channel Power (dBm)	Total rms Deviation (Hz)	f_L Baseband Frequencies (Hz) lowest	f_H Highest	Modulation Index	Bandwidth (Hz)
1.9/6.7 GHz Bands							
780	140	-19.6	407	60	3204	0.175	10
600	140	-15.0	610	60	2540	0.240	10
480	200	-15.0	779	60	2044	0.300	10
300	200	-15.0	616	60	1300	0.470	10
120	200	-15.0	464	60	552	0.840	10
120	200	-15.0	464	60	552	0.840	5
300	175	-19.6	319	60	1300	0.245	5
"Grandfathered" 1.9 GHz Band							
600	88	-15.0	301	60	2540	0.15	0
420	160	-15.0	561	60	1000	0.32	0
2130 MHz and 2100 MHz 2200 MHz Band							
132	47	-19.6	66	12	552	0.12	1.6
96	47	-15.0	104	12	408	0.25	1.6
72	60	-15.0	126	12	300	0.42	1.6
48	25	-15.0	50	12	204	0.24	0.8
24	42	-15.0	70	12	108	0.72	0.8
32.5/33.0 GHz Band							
1200	140	-15.0	866	564	5772	0.15	20/25
600	200	-15.0	871	60	2540	0.34	20/25
300	200	-15.0	616	60	1300	0.47	20/25
300	200	-15.0	616	60	1300	0.47	10/12.5

219

20/25
20/25
20/25
10/12.5

Table A-1 Modulation Parameters

Table 2.0-1

220

A	B	C	D	E	F	G	H	I
1	LAD INTERFERENCE DATA by JOHN SANELLI 07/JUN/92							
2	Notes:							
3	Shading denotes squelch bypassed.							
4	Italics Indicates Mini-circuits amplifier is in line.							
5		110P	110P	110P	110P	110P	110P	110P
6		UNLOADED	UNLOADED	UNLOADED	UNLOADED	UNLOADED	UNLOADED	UNLOADED
7								
8	CKT	NOISE BAND	BASEBAND RE	RF POWER FOR	RF POWER FOR	RF POWER FOR	RF POWER FOR	RF POWER FOR
9	L	0.1 HPSK		1 dB	6 dB	10 dB	20 dB	
10	L	0.1 FM						
11	L	0.1 QUASINO						
12	L	0.2						
13	L	0.5						
14	L	1.25						
15	L	5						
16	L	10						
17	M	0.1 HPSK						
18	M	0.1 FM						
19	M	0.1 QUASINO						
20	M	0.2						
21	M	0.5						
22	M	1.25						
23	M	5						
24	M	10						
25	H	0.1 HPSK						
26	H	0.1 FM						
27	H	0.1 QUASINO						
28	H	0.2						
29	H	0.5						
30	H	1.25						
31	H	5						
32	H	10						

Low

Medium

High

Table 2.1.2-1

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22JUNLAB.XLA

Voice Circuit	Interference Type	Relative RF Power Required to Cause Stated Voice Channel Degradation (db)					
		1 db	3 db	6 db	10 db	20 db	30 db
LOW	100 kHz SPK	0.0	0.0	0.0	0.0	0.0	0.0
LOW	100 kHz TN	2.3	1.3	1.7	4.1	1.6	1.6
LOW	100 kHz QUASE NOISE	0.1	-0.4	0.2	2.6	0.3	0.3
LOW	200 kHz	3.3	2.1	2.8	5.2	2.8	2.8
LOW	500 kHz	5.9	4.7	5.6	8.0	5.6	5.6
LOW	1.25 MHz	10.4	8.9	9.6	12.3	10.4	10.4
LOW	5 MHz	16.3	15.7	16.0	18.3	14.4	14.4
LOW	10 MHz	20.2	18.7	19.0	21.2	16.6	16.6
MEDIUM	100 kHz SPK	0.0	0.0	0.0	0.0	0.0	0.0
MEDIUM	100 kHz TN	3.4	4.0	4.1	4.2	3.6	3.6
MEDIUM	100 kHz QUASE NOISE	0.9	2.0	2.3	2.5	2.2	2.2
MEDIUM	200 kHz	9.3	7.1	6.2	8.7	4.9	4.9
MEDIUM	500 kHz	10.6	9.3	8.9	8.6	6.3	6.3
MEDIUM	1.25 MHz	11.7	11.2	11.0	11.1	10.6	10.6
MEDIUM	5 MHz	15.7	16.1	16.2	16.4	16.3	16.3
MEDIUM	10 MHz	18.1	19.1	19.4	19.7	19.6	19.6
HIGH	100 kHz SPK	0.0	0.0	0.0	0.0	0.0	0.0
HIGH	100 kHz TN	2.2	2.1	1.8	1.7	1.0	1.0
HIGH	100 kHz QUASE NOISE	-0.1	0.4	0.2	0.2	0.1	0.1
HIGH	200 kHz	1.8	2.7	3.0	2.9	2.9	2.9
HIGH	500 kHz	5.3	6.5	6.7	6.6	6.3	6.3
HIGH	1.25 MHz	9.0	10.3	10.8	10.6	11.0	11.0
HIGH	5 MHz	12.9	14.3	14.6	14.7	15.3	15.3
HIGH	10 MHz	16.5	17.5	17.6	17.6	18.3	18.3

Table 2.1.2-1: "Unloaded" Speech Test Interference Results

222

DISTANCE FROM MAIN BEAM (MILES)	OFFSET FROM MAIN BEAM (DEG.)	INTERFERENCE TYPE (MHz)	EIRP (mW) FOR DEGRADATION OF:		MAX VAN EIRP (mW)
			I dB	J dB	
13.0	-30	CW	1.50	5.62	2455
13.0	-30	100 kHz DPSK	44.67	173.70	501
13.0	-30	10 MHz	n	n	501
7.5	-34	CW	0.15	0.95	2455
7.5	-34	100 kHz DPSK	8.32	38.90	501
7.5	-34	10 MHz	n	n	501
6.3	-45	100 kHz DPSK	7.08	23.44	501
6.3	-45	10 MHz	478.63	n	501
5.9	-60	100 kHz DPSK	9.12	43.65	501
5.9	-60	10 MHz	n	n	501
4.7	-63	100 kHz DPSK	61.66	489.70	501
4.7	-63	10 MHz	n	n	501
3.8	-57	100 kHz DPSK	13.80	54.95	501
3.8	-57	10 MHz	n	n	501

Notes: n denotes insufficient power available in van.
high voice circuit

TABLE 2.2-1aa UNLOADED FIELD TEST RESULTS (INTERFERENCE)
(full link power)

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DISTANCE FROM MAIN BEAM (MILES)	OFFSET FROM MAIN BEAM (DEG.)	INTERFERENCE TYPE (MHz)	NIRP (mW) FOR DEGRADATION OF:		MAX VAN NIRP (mW)
			1 dB	3 dB	
6.9	-09	100 kHz BPSK	44.7	141.3	501
6.9	-09	10 MHz	n	n	501
4.7	-63	100 kHz BPSK	77.6	n	501
4.7	-63	10 MHz	n	n	501
3.8	-57	100 kHz BPSK	44.7	331.8	501
3.8	-57	10 MHz	n	n	501

Notes: n denotes insufficient power available in van.
high voice circuit

TABLE 2.2-1ab UNLOADED FIELD TEST RESULTS (INTERFERENCE)
(link power reduced by 10 dB)

What is claimed is:

1. An apparatus for multi-band multi-mode communication
5 comprising:

a transmitter, said transmitter having a plurality of
transmission modes and a plurality of output frequency bands;
and

a receiver co-located with said transmitter, said
10 receiver having a plurality of reception modes and a plurality
of input frequency bands.

2. The apparatus of claim 1 wherein said plurality of
transmission and reception modes comprises a spread spectrum
15 mode.

3. The apparatus of claim 1 wherein said plurality of
transmission and reception modes comprise a narrowband mode.

4. The apparatus of claim 1 wherein said plurality of
20 input and output frequency bands comprise a frequency band
which spans from 2400 megahertz to 2483.5 megahertz.

5. The apparatus of claim 1 wherein said plurality of
25 input and output frequency bands comprise a frequency band
which spans from 1850 megahertz to 1990 megahertz.

6. The apparatus of claim 1 wherein said receiver and
said transmitter are co-located in a mobile handset.
30

7. The apparatus of claim 1 wherein said plurality of
transmission and reception modes comprise a cellular mode.

8. The apparatus of claim 1 wherein said plurality of
35 transmission and reception modes comprise a microcellular
mode.

9. The apparatus of claim 1 wherein said plurality of transmission modes comprises a communications protocol selected from the group consisting of: AMPS, GSM, IS-45, IS-95 and DECT.

5

10. The apparatus of claim 1 wherein said plurality of reception modes comprises a communications protocol selected from the group consisting of: AMPS, GSM, IS-45, IS-95 and DECT.

10

11. The apparatus of claim 1 further comprising a paging unit.

12. An apparatus for multi-band multi-mode communication comprising:

15

a transmitter comprising

a first tunable frequency source;

a plurality of modulators coupled to said first tunable frequency source, said plurality of modulators comprising a plurality of transmission modes;

20

a first mode selection signal coupled to each of said plurality of modulators;

25

a first filter coupled to an output of each of said plurality of modulators; and

a receiver comprising

a second filter;

30

a second tunable frequency source;

a frequency converter coupled to said second filter and coupled to said second tunable frequency source;

a plurality of demodulators coupled to said frequency converter, said plurality of demodulators comprising a plurality of reception modes

35

a second mode select signal coupled to each of said plurality of demodulators.

13. The apparatus of claim 12 wherein said plurality of
5 demodulators comprise a spread spectrum demodulator and a narrowband demodulator.

14. The apparatus of claim 12 wherein said plurality of
modulators comprise a spread spectrum modulator and a
10 narrowband modulator.

15. The apparatus of claim 12 further comprising a mode
select switch which selects one of said plurality of
transmission modes.

16. The apparatus of claim 12 further comprising a mode
select switch which selects one of said plurality of reception
modes.

17. The apparatus of claim 12 wherein said transmitter
further comprises a power amplifier coupled to said plurality
of modulators, said power amplifier adjustable to operate in
each of said plurality of transmission modes.

18. The apparatus of claim 12 wherein at least one of
said first and second tunable frequency sources comprises a
programmable frequency synthesizer.

19. The apparatus of claim 12 wherein said first filter
30 is capable of passing a signal in each of said plurality of
transmission modes.

20. The apparatus of claim 12 wherein said second filter
is capable of passing a signal in each of said plurality of
35 reception modes.

21. The apparatus of claim 12 wherein said first and second filters comprise center filtering frequencies in a plurality of frequency bands.

5 22. The apparatus of claim 12 wherein at least one of said first and second filters comprises an adjustable bandpass filter.

10 23. The apparatus of claim 12 wherein at least one of said first and second filters comprises a plurality of bandpass filters in parallel.

15 24. The apparatus of claim 12 wherein said first filter comprises a plurality of narrowband power amplifiers in parallel, said plurality of narrowband power amplifiers coupled to a multiplexer.

20 25. An apparatus for receiving spread spectrum signals comprising:
 an antenna for receiving a spread spectrum signal transmitted at a first frequency;
 a frequency synthesizer outputting a synthesized signal comprising a second frequency;
 a filter coupled to said spread spectrum signal, said
25 filter selectively outputting a filtered signal, said filtered signal comprising a first frequency range and a second frequency range;
 a multiplier coupled to said filtered signal and said synthesized signal, said multiplier outputting a multiplied
30 signal;
 a spread spectrum demodulator coupled to said multiplied signal.

35 26. The apparatus of claim 25 wherein said frequency synthesizer comprises:
 a reference frequency signal source;
 a programmable divide-by-N counter;

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a multiplier having inputs coupled to said programmable divide-by-N counter and said reference frequency signal source; and

5 a voltage-controlled oscillator having an input coupled to said multiplier, said voltage-controlled oscillator having an output coupled to said programmable divide-by-N counter.

27. The apparatus of claim 25 wherein a plurality of frequency bands are monitored at once.

10

28. The apparatus of claim 25 wherein:

said first frequency range is defined by the summation of said first frequency and said second frequency, and

15 said second frequency range is defined by a difference between said first frequency and said second frequency.

29. The apparatus of claim 28 wherein said second frequency range is defined by the subtraction of said first frequency from said second frequency.

20

30. The apparatus of claim 28 wherein said second frequency range is defined by the subtraction of said second frequency from said first frequency.

25 31. The apparatus of claim 28 wherein said filter comprises:

a first band pass filter having a center filtering frequency defined by the summation of said first frequency and said second frequency, and

30 a second band pass filter having a center filtering frequency defined by a difference between said first frequency and said second frequency.

32. The apparatus of claim 31 further comprising at least one switch coupled to an output of said first band pass filter and an output of said second band pass filter.

35

33. The apparatus of claim 31 further comprising at least one switch coupled to an input of said first band pass filter and an input of said second band pass filter.

5 34. A method for receiving spread spectrum signals comprising the steps of:

receiving a spread spectrum signal transmitted at a first frequency;

10 generating with a frequency synthesizer a synthesized signal comprising a second frequency;

filtering said spread spectrum signal and selectively outputting a filtered signal, said filtered signal comprising a first frequency range and a second frequency range;

15 multiplying said filtered signal and said synthesized signal, and outputting a multiplied signal; and
spread spectrum demodulating said multiplied signal.

35. The method of claim 34 wherein:

20 said first frequency range is defined by the summation of said first frequency and said second frequency, and

said second frequency range is defined by a difference between said first frequency and said second frequency.

25 36. The method of claim 35 wherein said filtering step comprises:

band pass filtering said spread spectrum signal with a center filtering frequency defined by the summation of said first frequency and said second frequency, and

30 band pass filtering said spread spectrum signal with a center filtering frequency defined by a difference between said first frequency and said second frequency.

37. A method for receiving multi-band spread spectrum signals comprising the steps of:

35 receiving a spread spectrum signal having a first frequency;

generating with a frequency synthesizer a synthesized signal comprising a second frequency;

filtering said spread spectrum signal and outputting a first filtered signal and a second filtered signal, said first
5 filtered signal falling within a first frequency range defined by the summation of said first frequency and said second frequency, said second filtered signal falling within a frequency range defined by a difference between said first frequency and said second frequency;

10 selectively modulating said first and second filtered signals with said synthesized signal and outputting a modulated signal; and

spread spectrum demodulating said modulated signal.

15 38. An apparatus for receiving spread spectrum signals comprising:

means for receiving a spread spectrum signal transmitted at a first frequency;

20 a frequency synthesizer outputting a synthesized signal comprising a second frequency;

a filter coupled to said spread spectrum signal, said filter outputting a filtered signal at either a first center frequency or a second center frequency, said first center frequency defined by the summation of said first frequency and
25 said second frequency and a second frequency range, said second frequency defined by a difference between said first frequency and said second frequency;

30 a multiplier coupled to said filtered signal and said synthesized signal, said multiplier outputting a multiplied signal;

a spread spectrum demodulator coupled to said multiplied signal.

35 39. An apparatus for multi-band spread-spectrum communication comprising:

a spread spectrum signal generator outputting a spread spectrum signal comprising a first frequency;

a frequency synthesizer outputting a synthesized signal comprising a second frequency;

a multiplier having an input coupled to said frequency synthesizer and an input coupled to said spread spectrum
5 signal generator, said multiplier generating a bimodal signal;

a filter coupled to said bimodal signal, said filter comprising a first and a second output frequency ranges;

said first output frequency range defined by the summation of said first frequency and said second frequency;

10 and

said second output frequency range defined by a difference between said first frequency and said second frequency.

15 40. The apparatus of claim 39 wherein said second output frequency range is defined by the subtraction of said first frequency from said second frequency.

20 41. The apparatus of claim 39 wherein said second output frequency range is defined by the subtraction of said second frequency from said first frequency.

42. The apparatus of claim 39 wherein said filter comprises:

25 a first band pass filter comprising a center filtering frequency defined by the summation of said first frequency and said second frequency; and

a second band pass filter comprising a center filtering frequency defined by a difference between said first frequency
30 and said second frequency.

43. The apparatus of claim 42 wherein said filter further comprises a wideband amplifier coupled to a band select signal.

35

44. The apparatus of claim 39 wherein said filter comprises:

a first narrowband power amplifier which operates at a frequency defined by the summation of said first frequency and said second frequency, said first narrowband power amplifier outputting a first amplified signal; and

5 a second narrowband power amplifier which operates at a frequency defined by a difference between said first frequency and said second frequency, said second narrowband power amplifier outputting a second amplified signal.

10 45. The apparatus of claim 44 wherein said filter further comprises a multiplexer having an input coupled to said first amplified signal and an input coupled to said second amplified signal, said multiplexer outputting one of said first or second amplified signals in response to a
15 control signal.

46. The apparatus of claim 44 wherein said filter further comprises at least one switch coupled to said first and second amplified signals, whereby one of said first or
20 second amplified signals is selected in response to a control signal.

47. The apparatus of claim 39 wherein said spread spectrum signal generator comprises:

25 a spread spectrum encoder;
a fixed signal source which generates a carrier signal;
and

a modulator having inputs coupled to said spread spectrum encoder and said fixed signal source.

30

48. The apparatus of claim 39 wherein said frequency synthesizer comprises:

a reference frequency signal source;
a programmable divide-by-N counter;

35 a multiplier having inputs coupled to said programmable divide-by-N counter and said reference frequency signal source; and

a voltage-controlled oscillator having an input coupled to said multiplier, said voltage-controlled oscillator having an output coupled to said programmable divide-by-N counter.

5 49. The apparatus of claim 39 wherein said first output frequency range spans from 2400 megahertz to 2483.5 megahertz.

10 50. The apparatus of claim 39 wherein said second output frequency range spans from 1850 megahertz to 1990 megahertz.

15 51. The apparatus of claim 39 wherein a signal having a frequency in both of said first and second output frequency ranges are transmitted at once.

20 52. The apparatus of claim 39 wherein
 said first output frequency range comprises a plurality of first frequency sub-bands;
 said second output frequency range comprises a plurality of second frequency sub-bands;
 each one of said first frequency sub-bands is paired with a corresponding one of said second frequency sub-bands to define a plurality of frequency pairs; and
 said second frequency is selected from a discrete group of frequencies corresponding to said plurality of frequency
25 pairs.

 53. A method for multi-band spread-spectrum communication comprising the steps of:
 generating a spread spectrum signal comprising a first
30 frequency;
 generating with a frequency synthesizer a synthesized signal comprising a second frequency;
 modulating said spread spectrum signal and said synthesized signal to generate a bimodal signal; and
35 filtering said bimodal signal to output a filtered signal having a first and a second output frequency ranges, said first output frequency range defined by the summation of said

first frequency and said second frequency, said second output frequency range defined by a difference between said first frequency and said second frequency.

5 54. The method of claim 53 further comprising the step of selecting one of said first or second output frequency ranges.

10 55. The method of claim 53 wherein said step of filtering comprises the steps of:

band pass filtering with a center filtering frequency defined by the sum of said first frequency and said second frequency; and

15 band pass filtering with a center filtering frequency defined by a difference between said first frequency and said second frequency.

56. The method of claim 53 wherein said step of filtering comprises the steps of:

20 amplifying said bimodal signal at a frequency defined by the summation of said first frequency and said second frequency and outputting a first amplified signal; and

25 amplifying said bimodal signal at a frequency defined a difference between said first frequency and said second frequency and outputting a second amplified signal.

57. The method of claim 56 wherein said step of filtering further comprises the steps of multiplexing said first and second amplified signals and outputting one of said
30 first or second amplified signals in response to a control signal.

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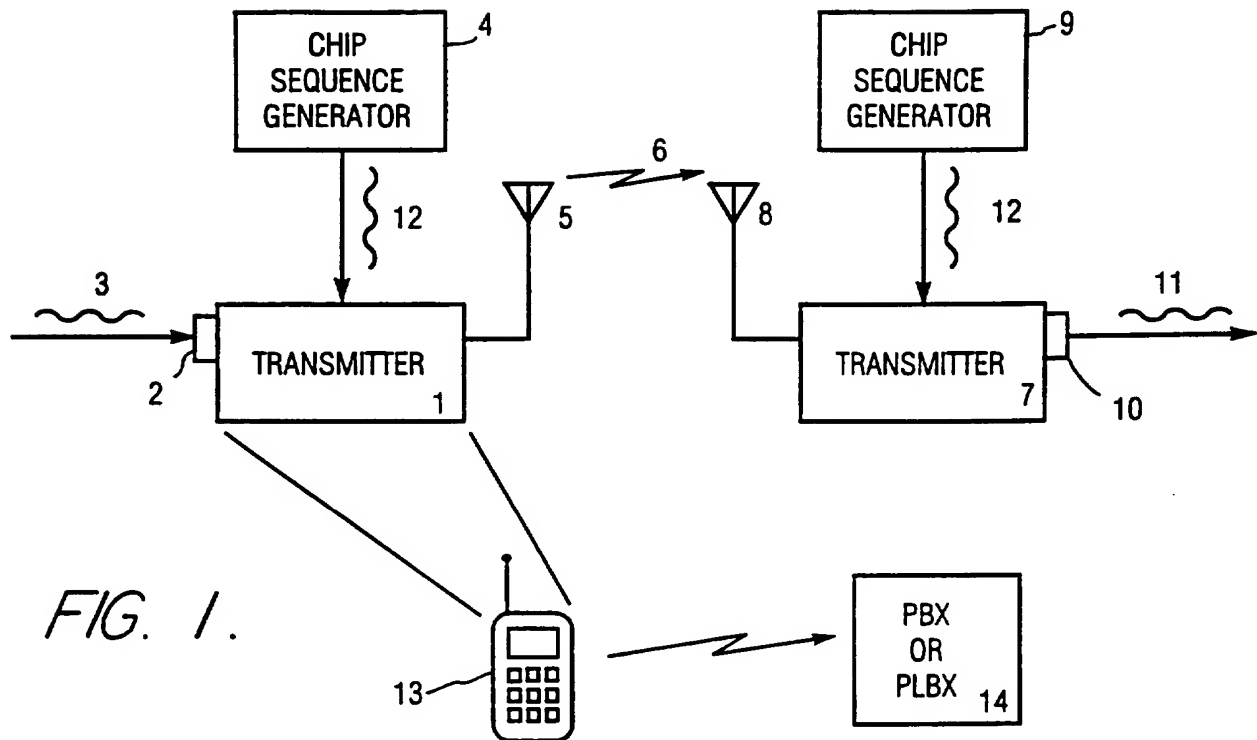


FIG. 1.

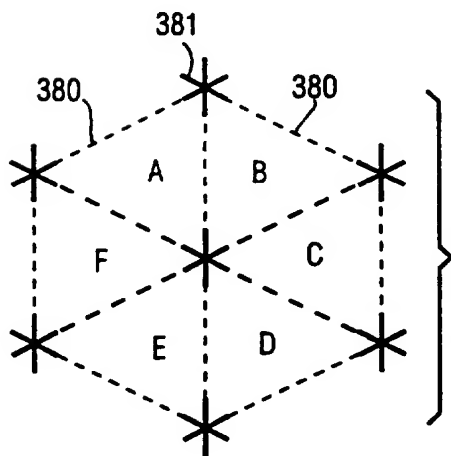


FIG. 6.

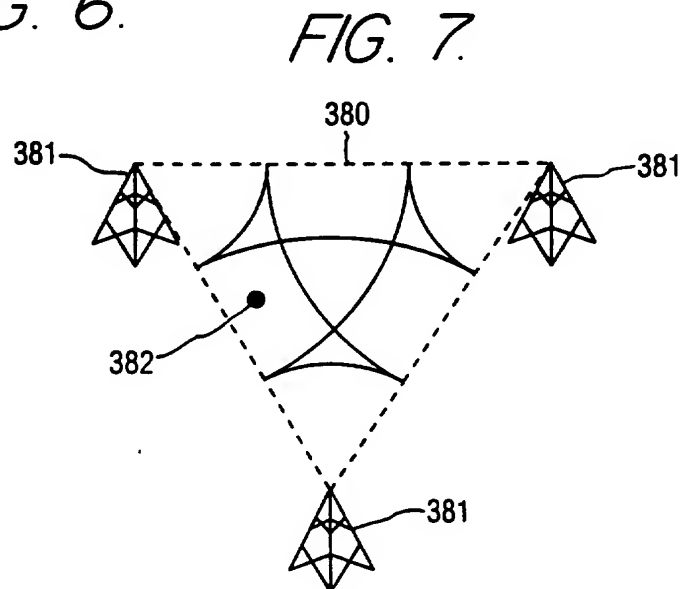


FIG. 7.

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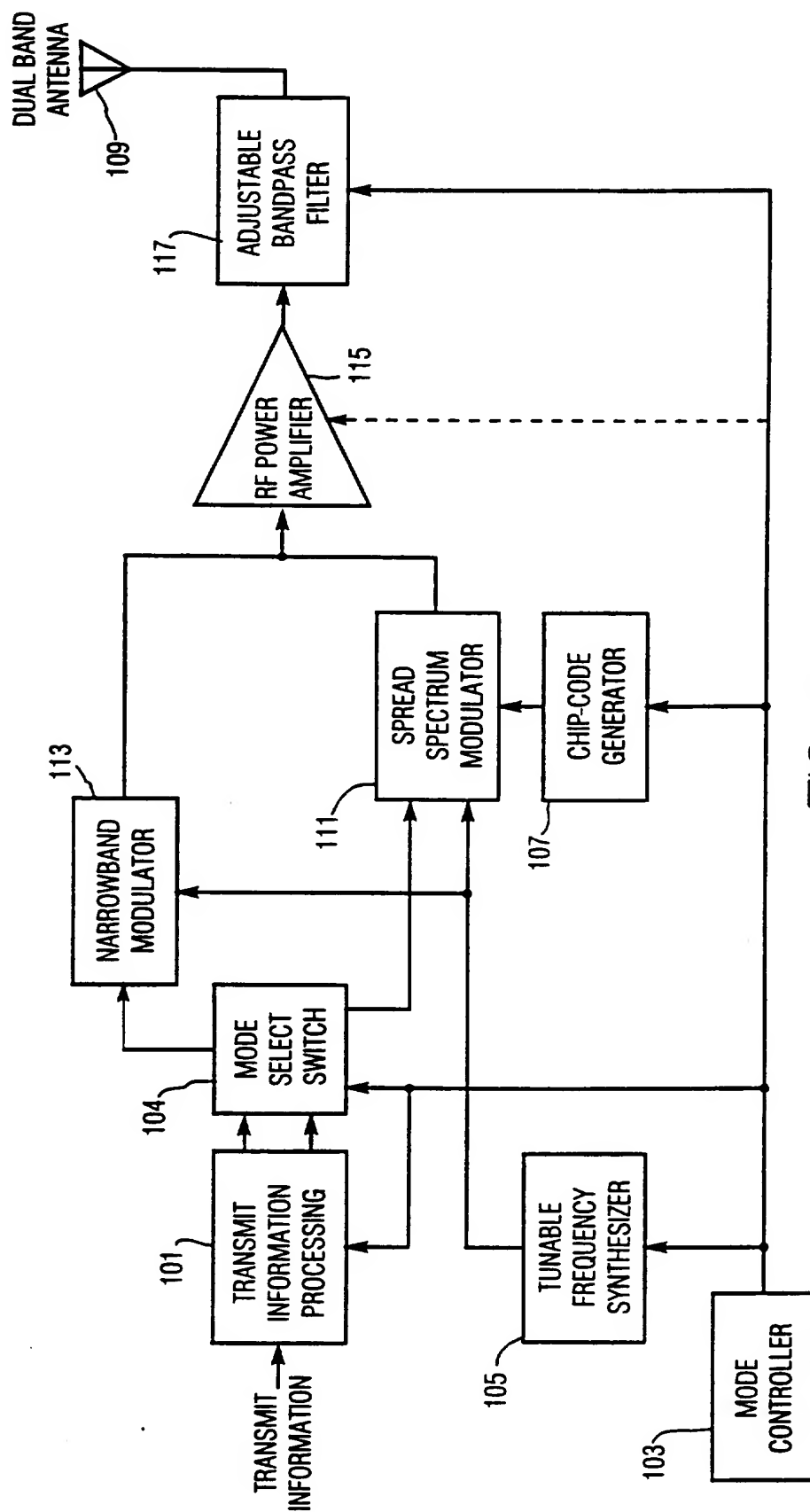


FIG. 2.

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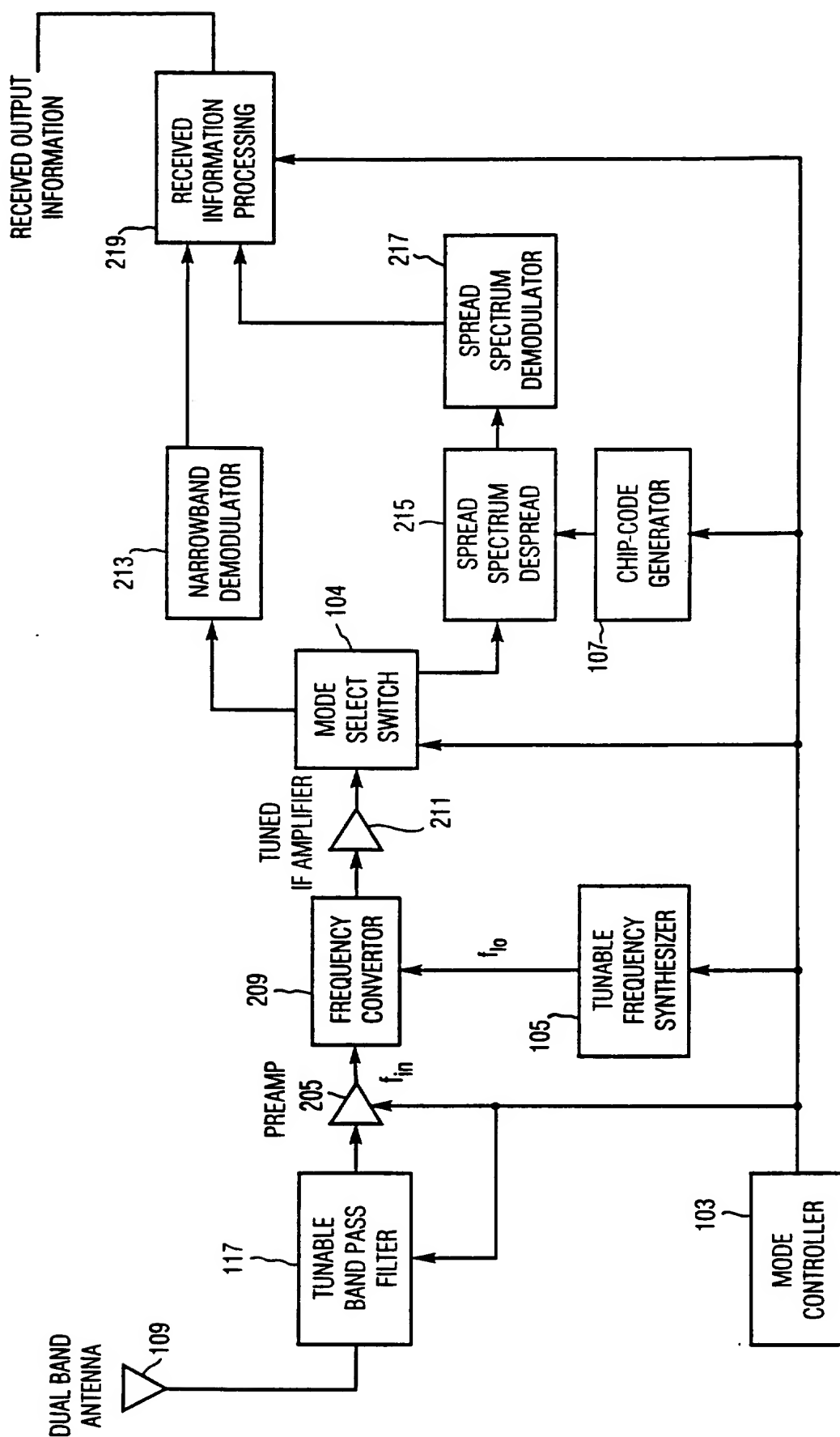


FIG. 3.

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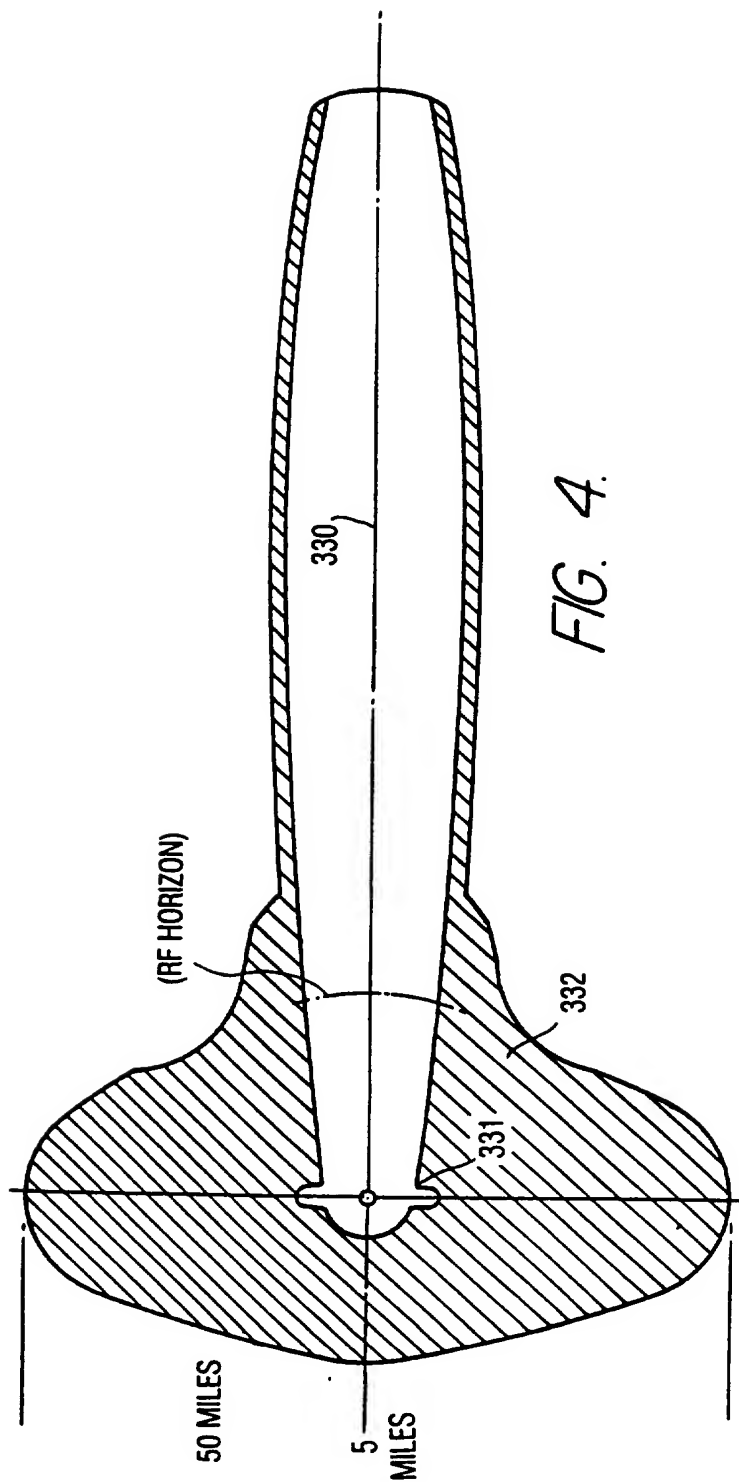


FIG. 4.

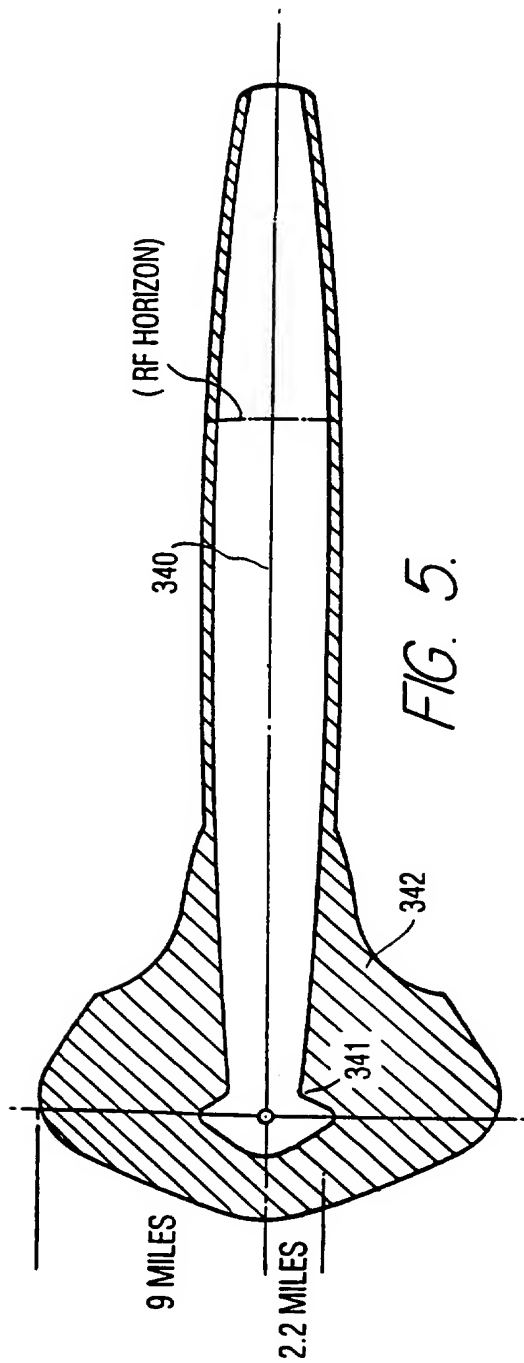


FIG. 5.

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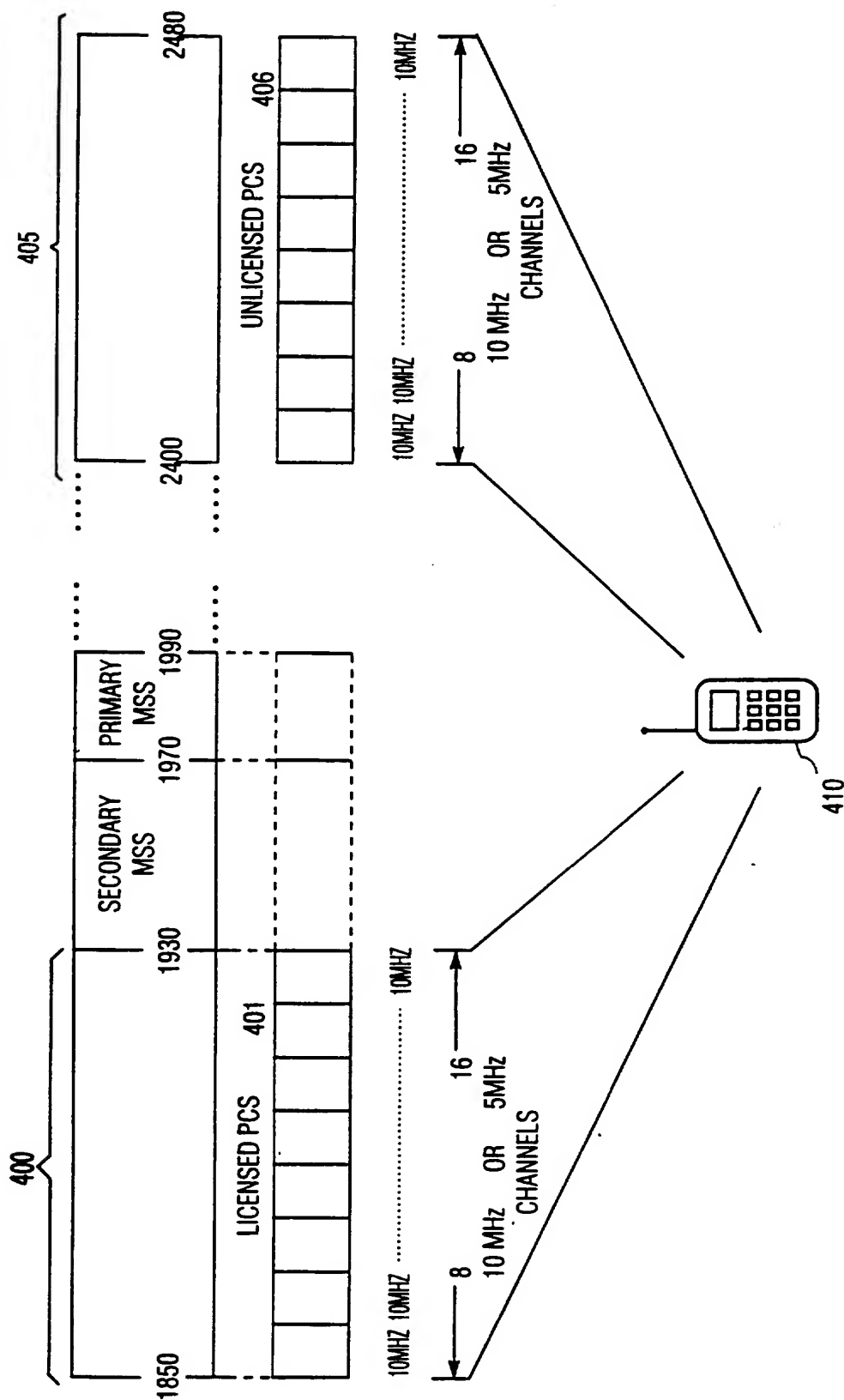


FIG. 8.

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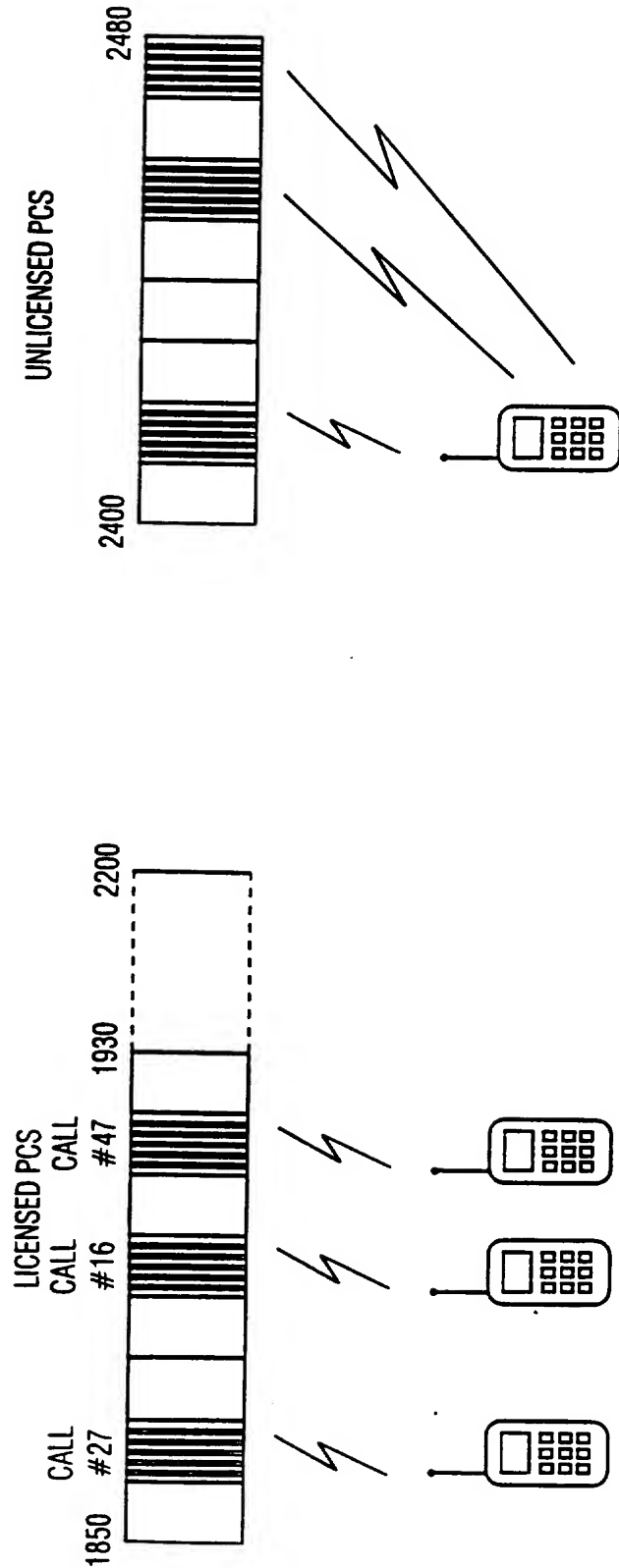


FIG. 9.

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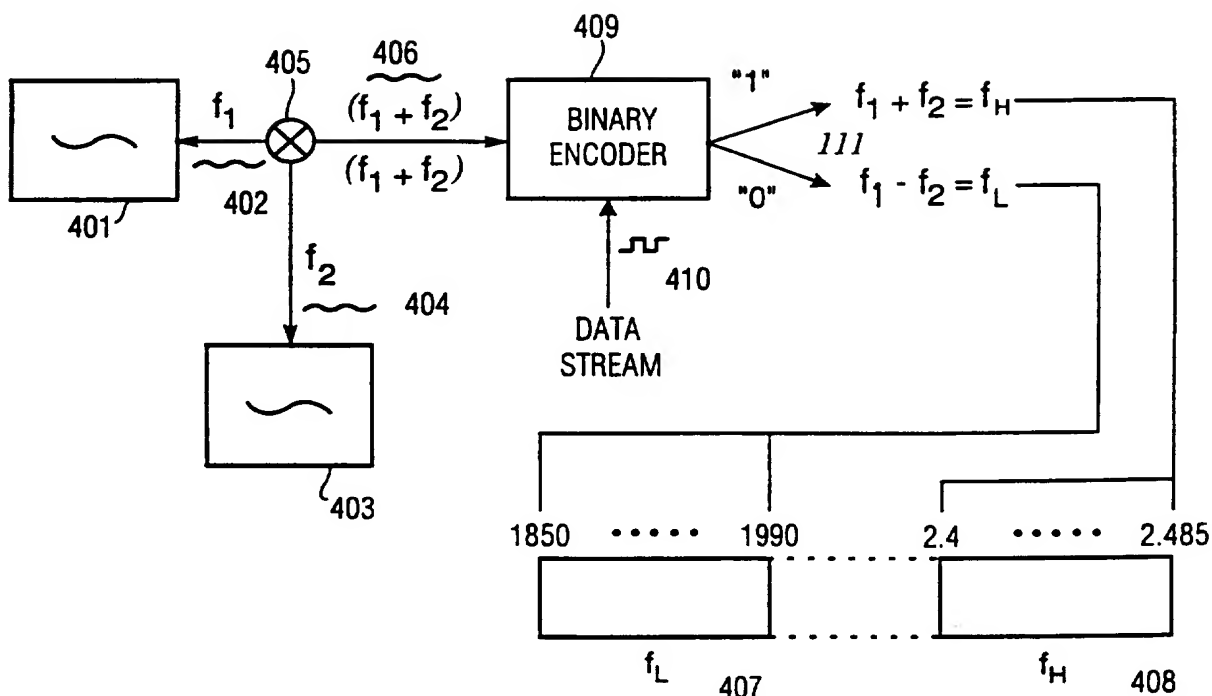
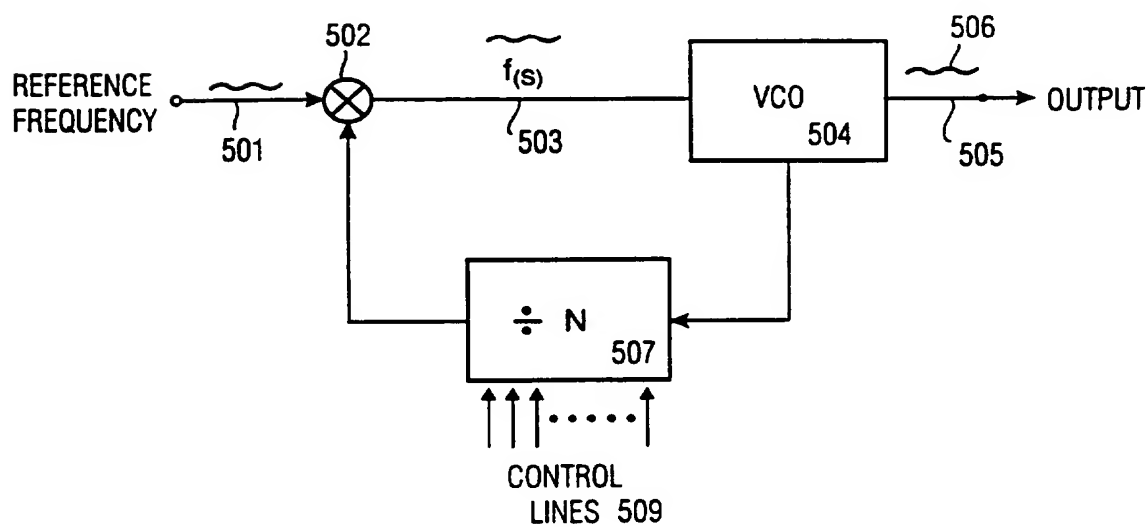


FIG. 10.

FIG. 11.



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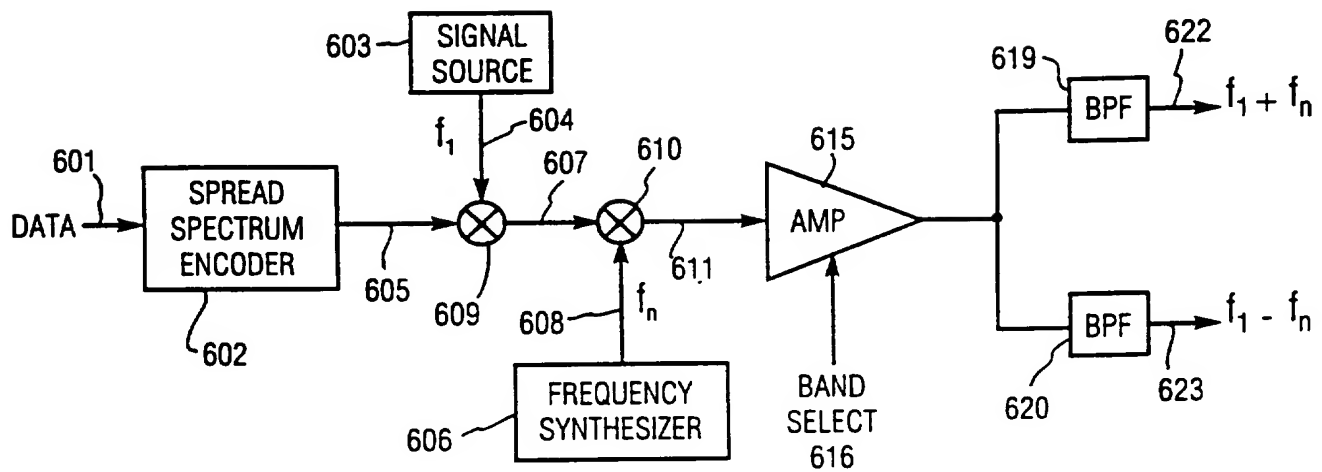


FIG. 12.

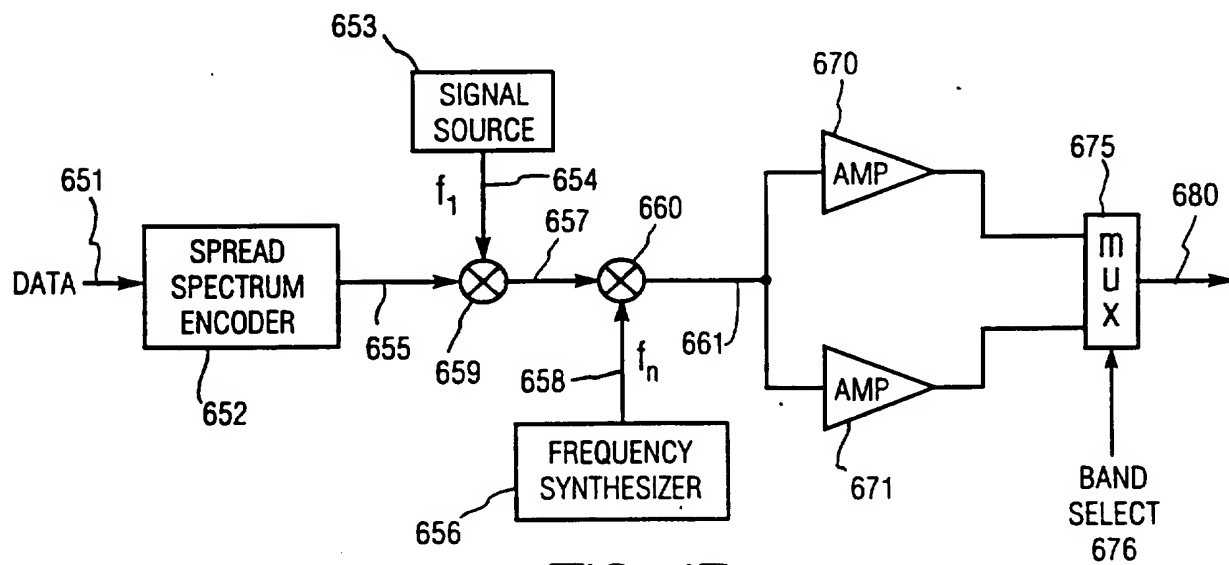
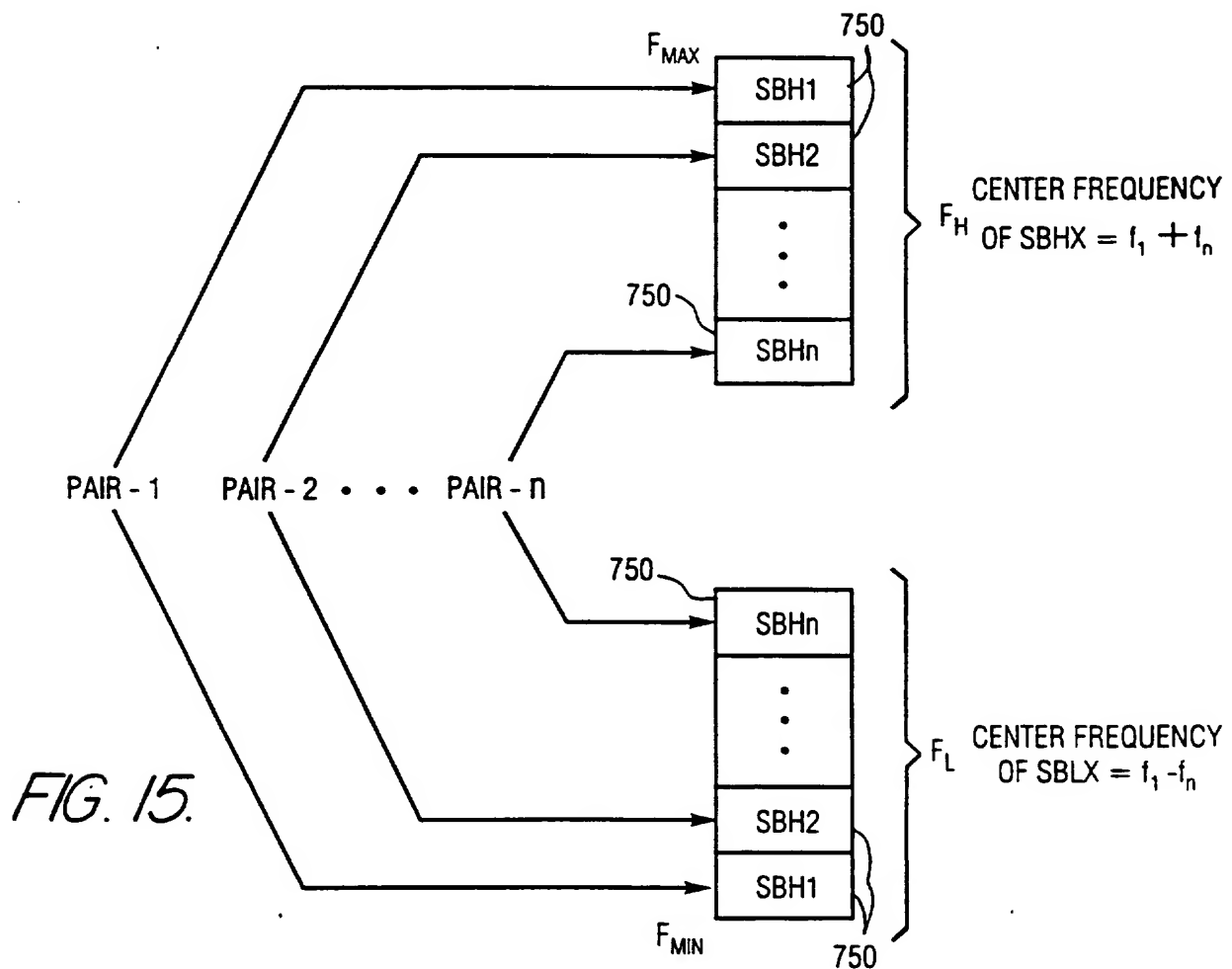
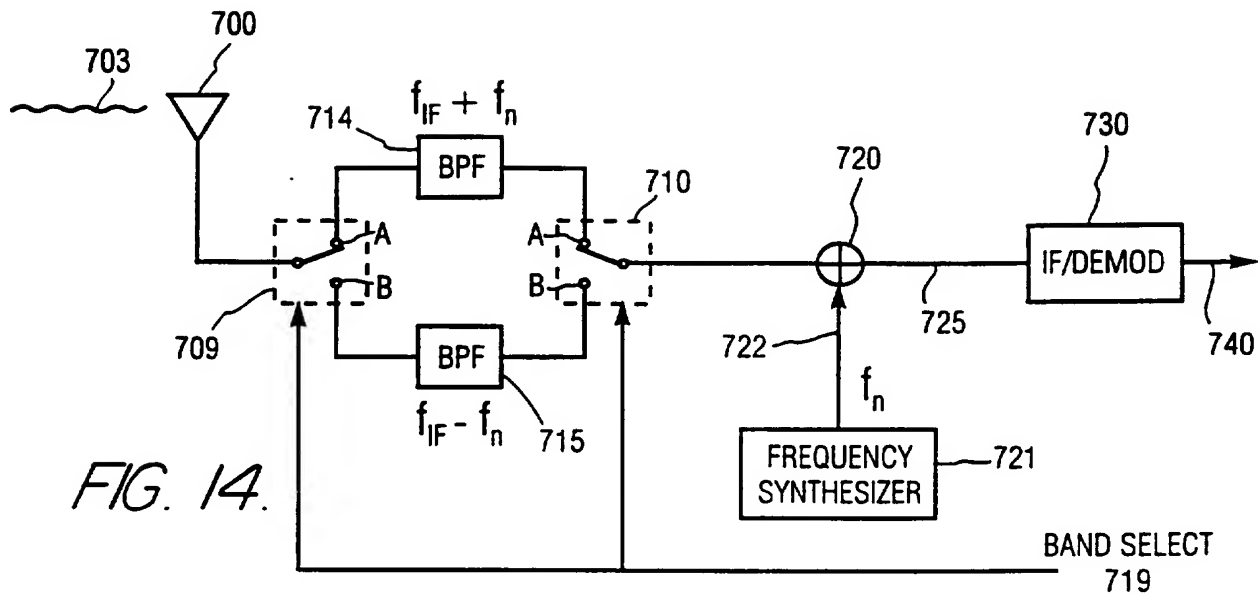


FIG. 13.

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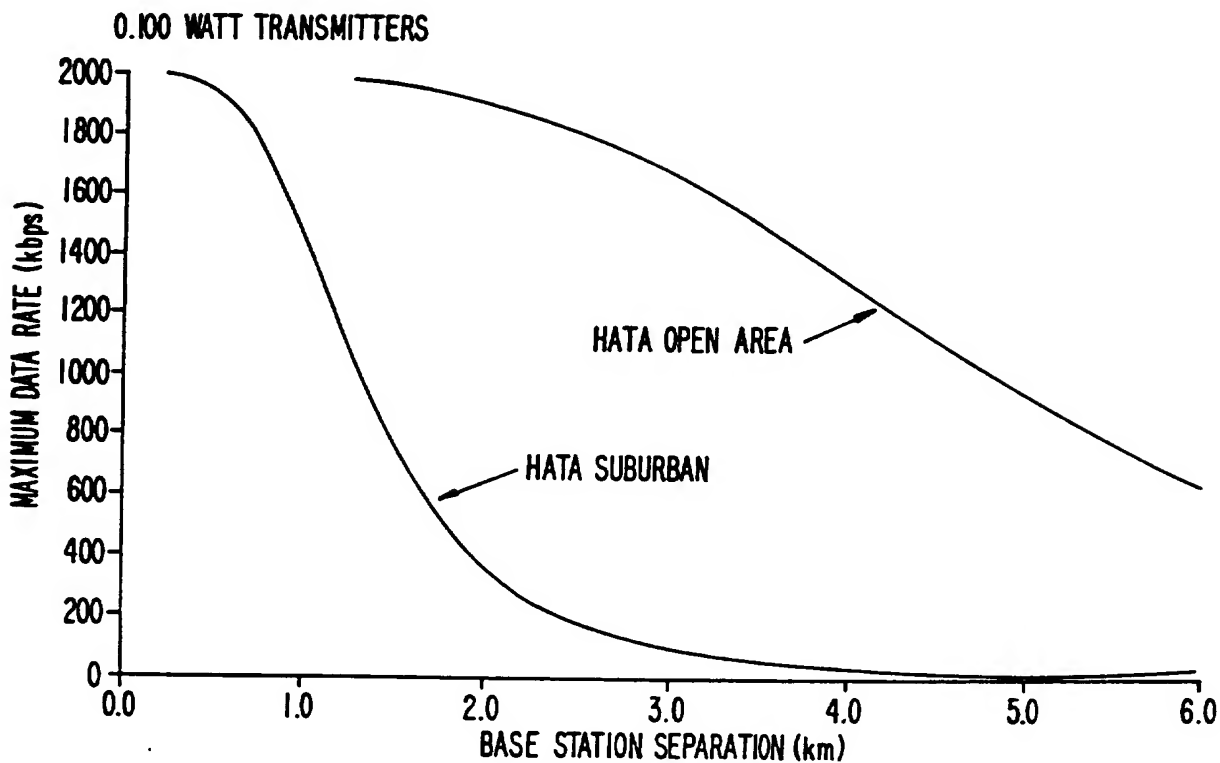


FIG. 16-1.

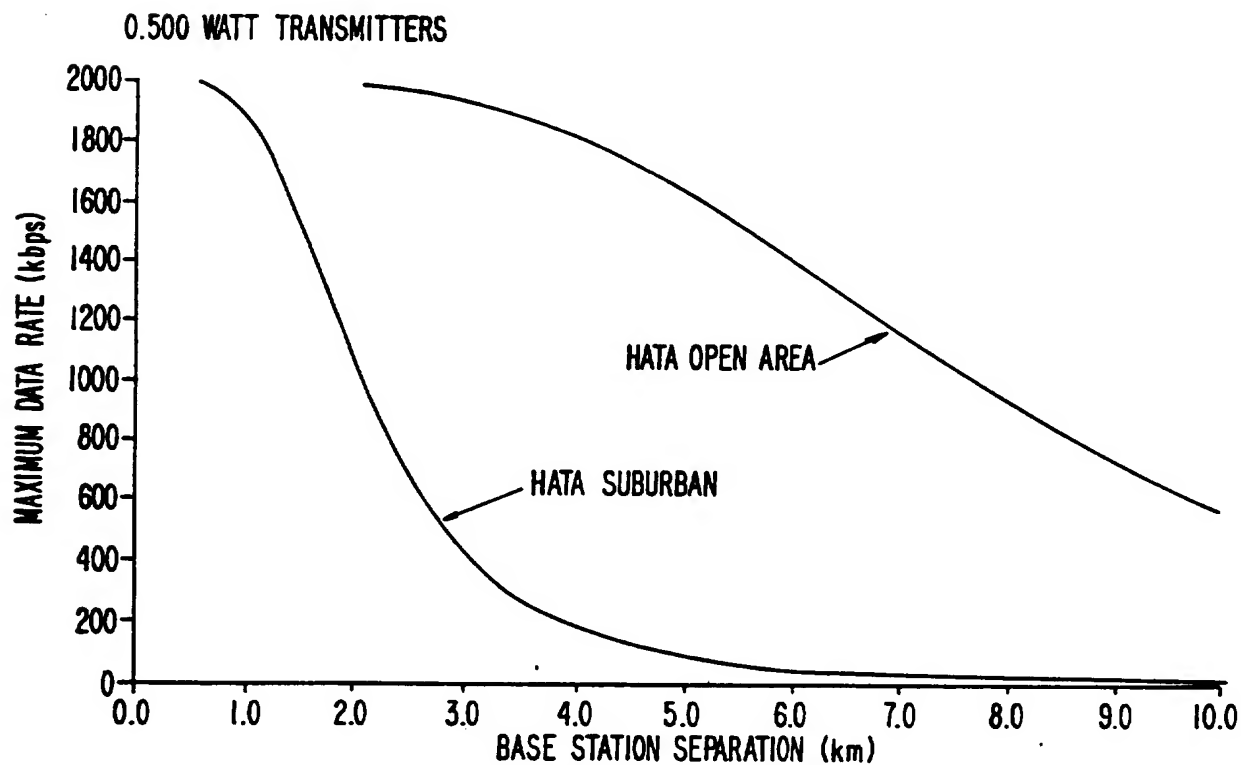


FIG. 16-2.

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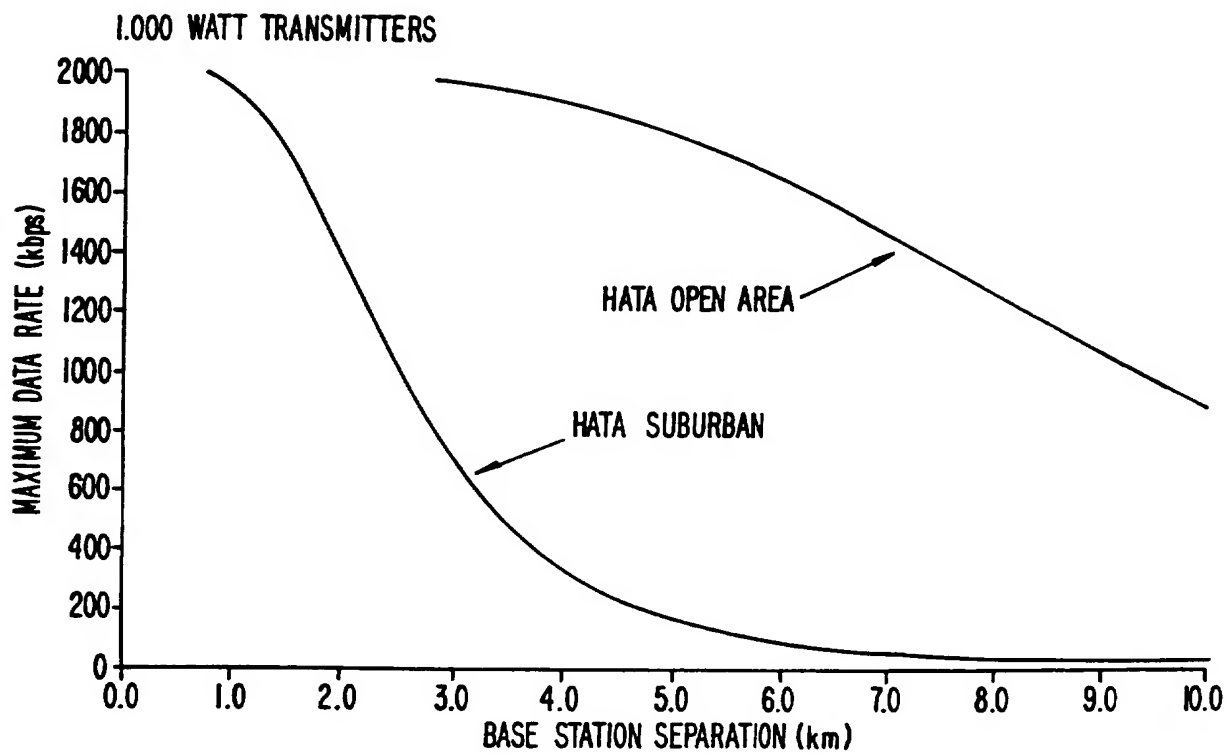


FIG. 16-3.

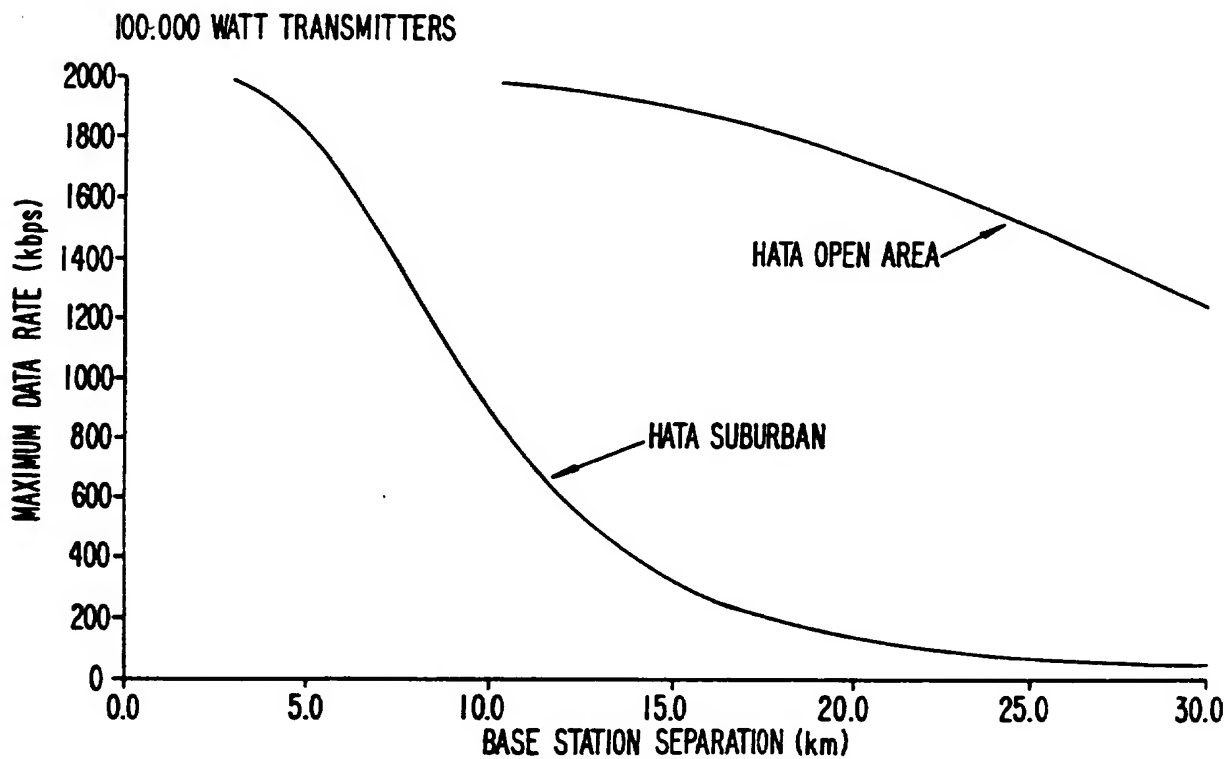


FIG. 16-4.

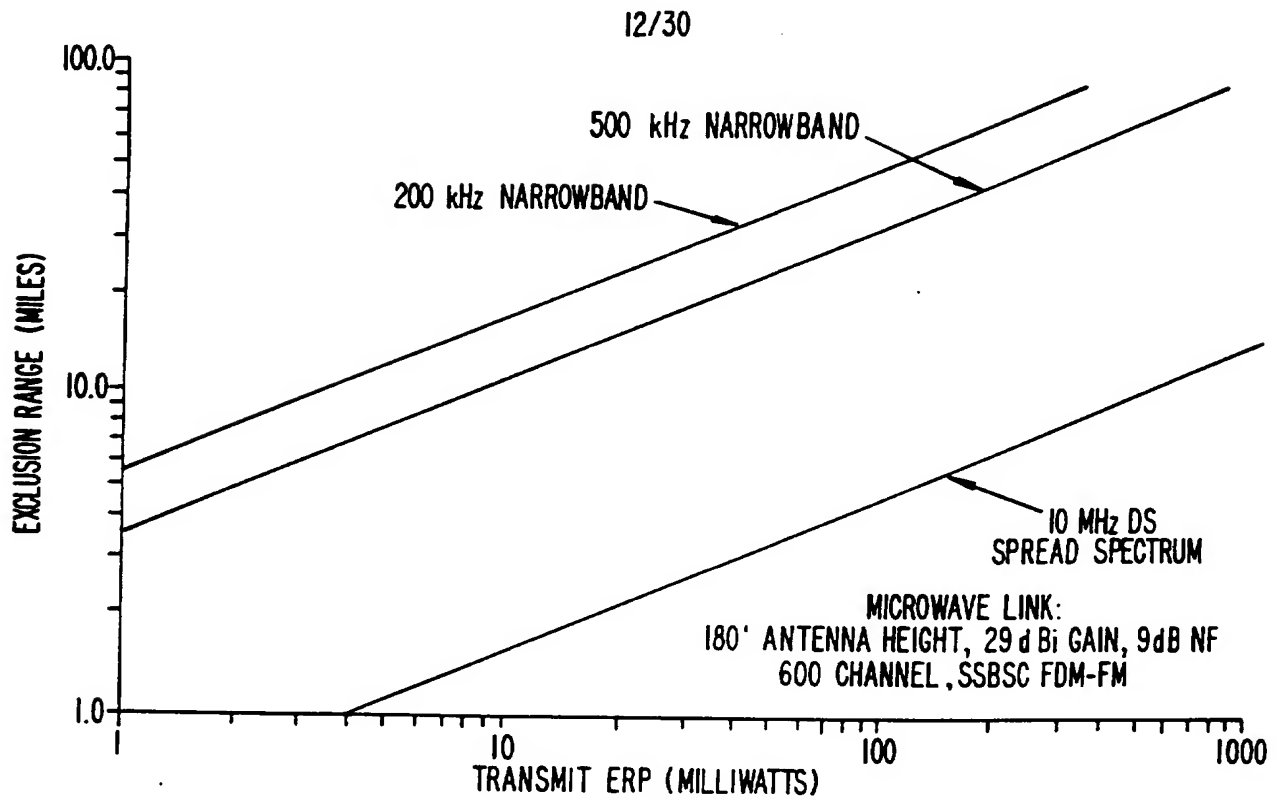
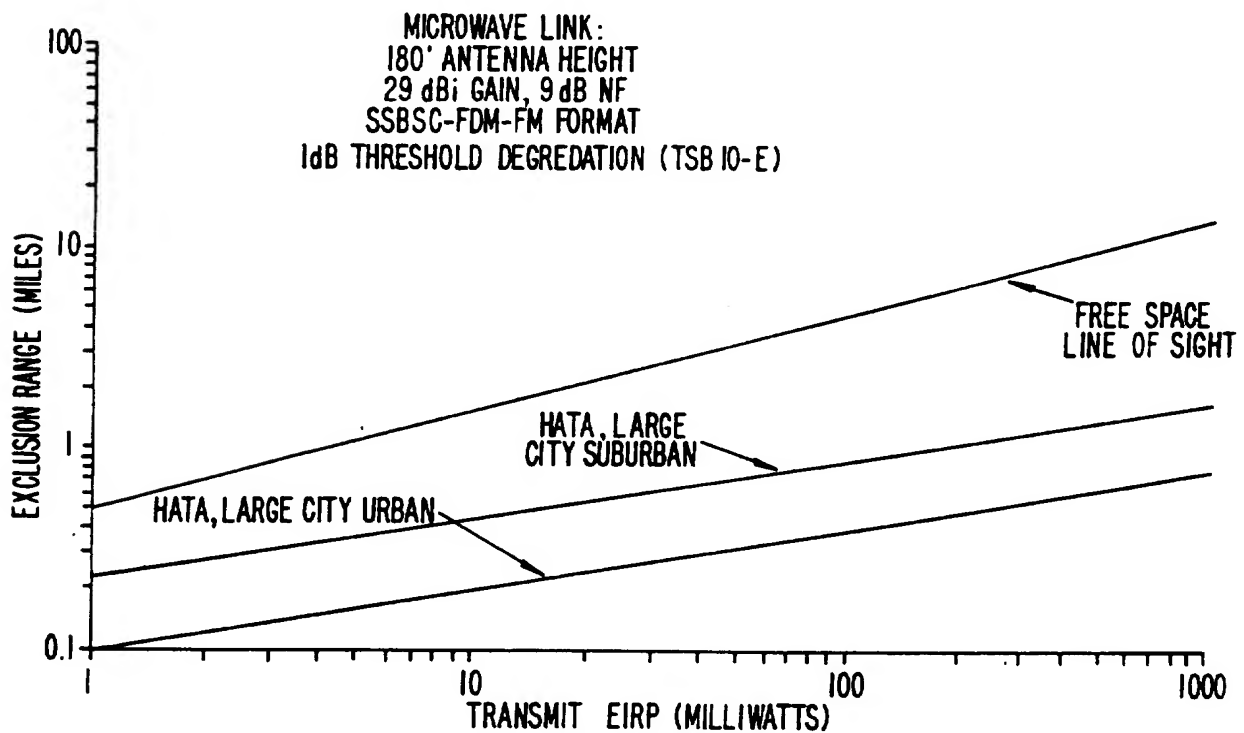
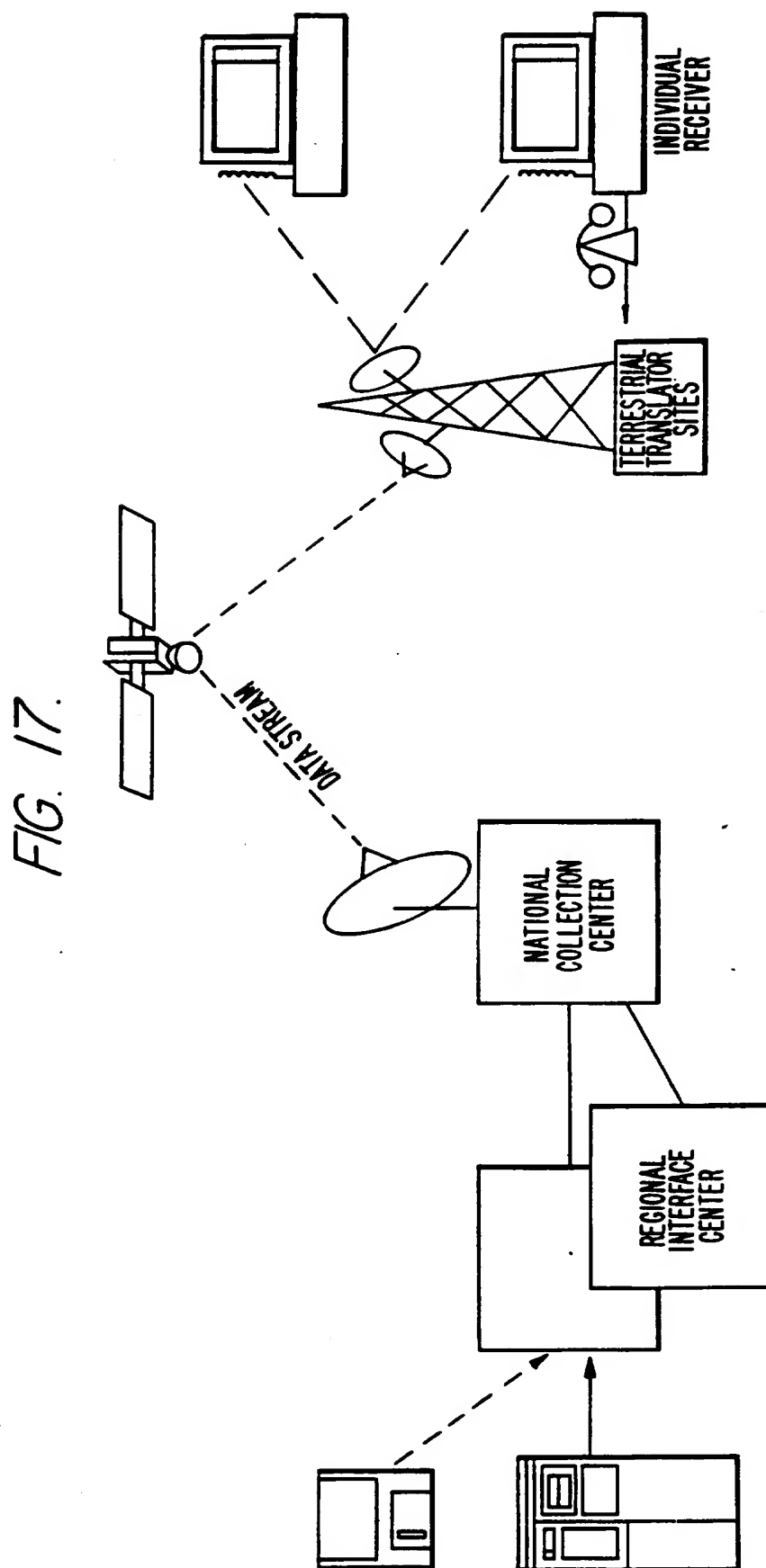


FIG. 16-5.

FIG. 16-6.
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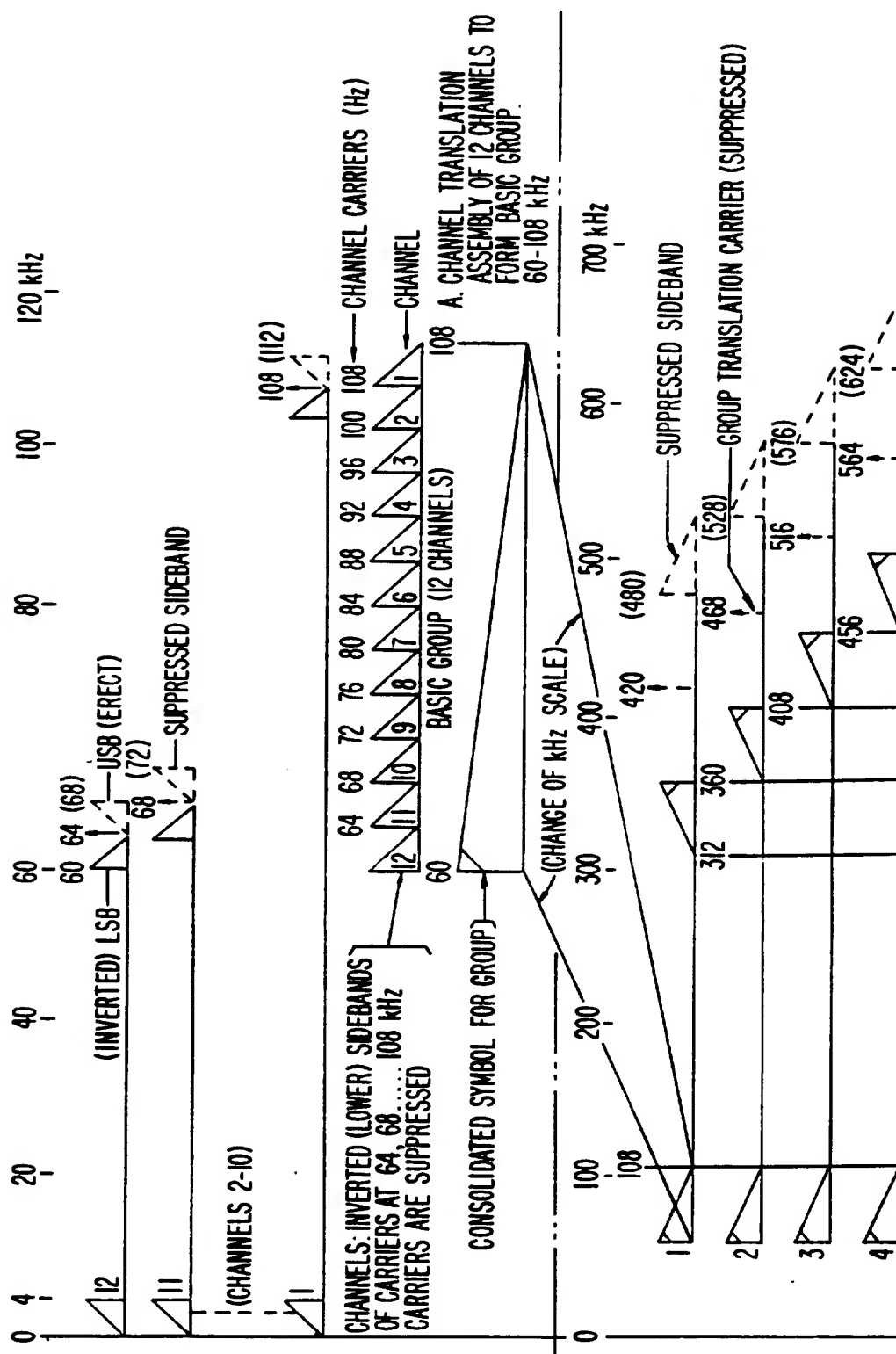


FIG. 18-1a.

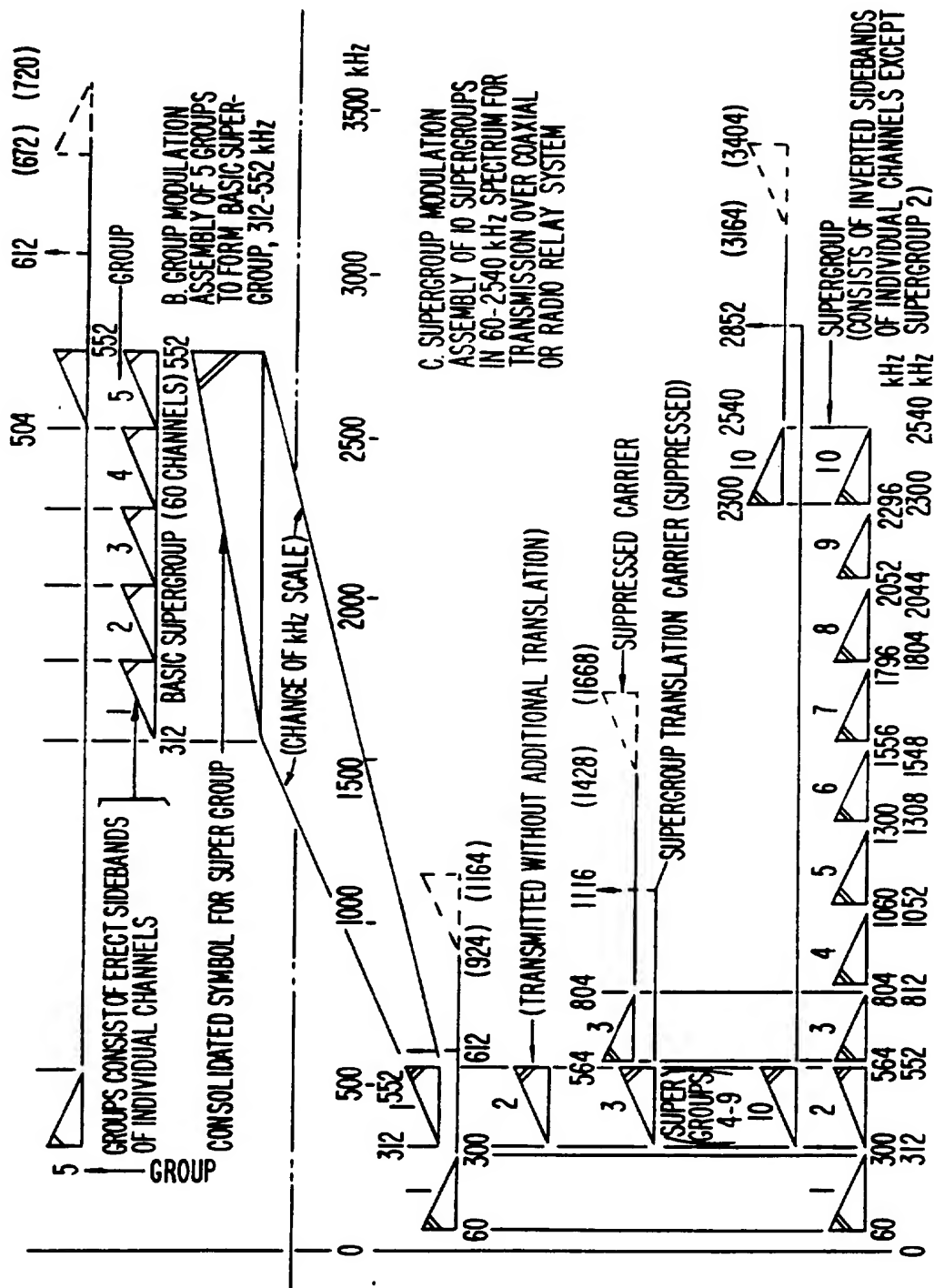


FIG. 18-1b.

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FIG. 18-2a.

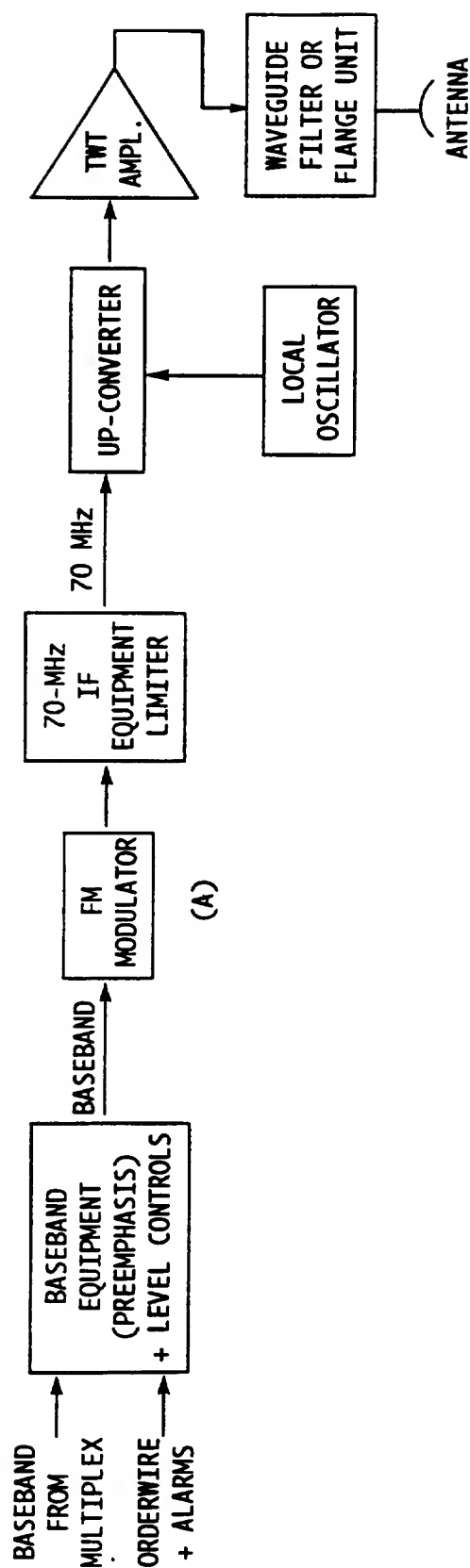
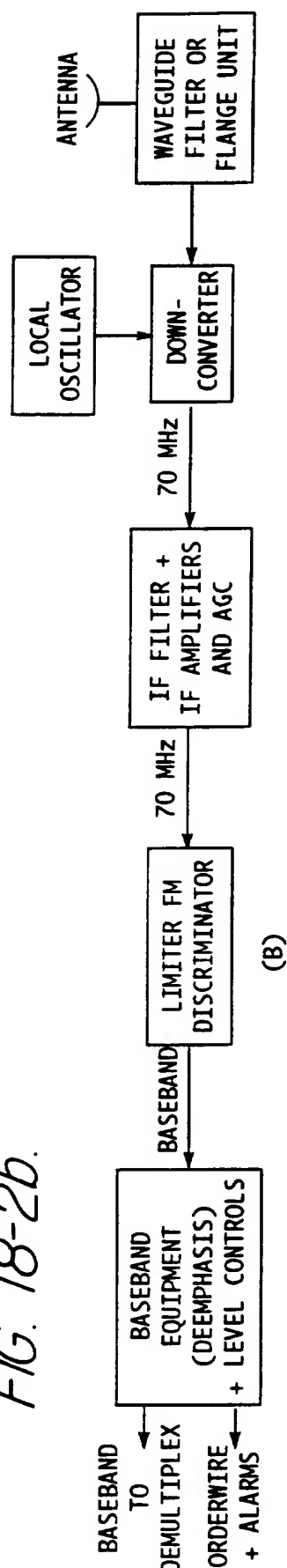


FIG. 18-2b.



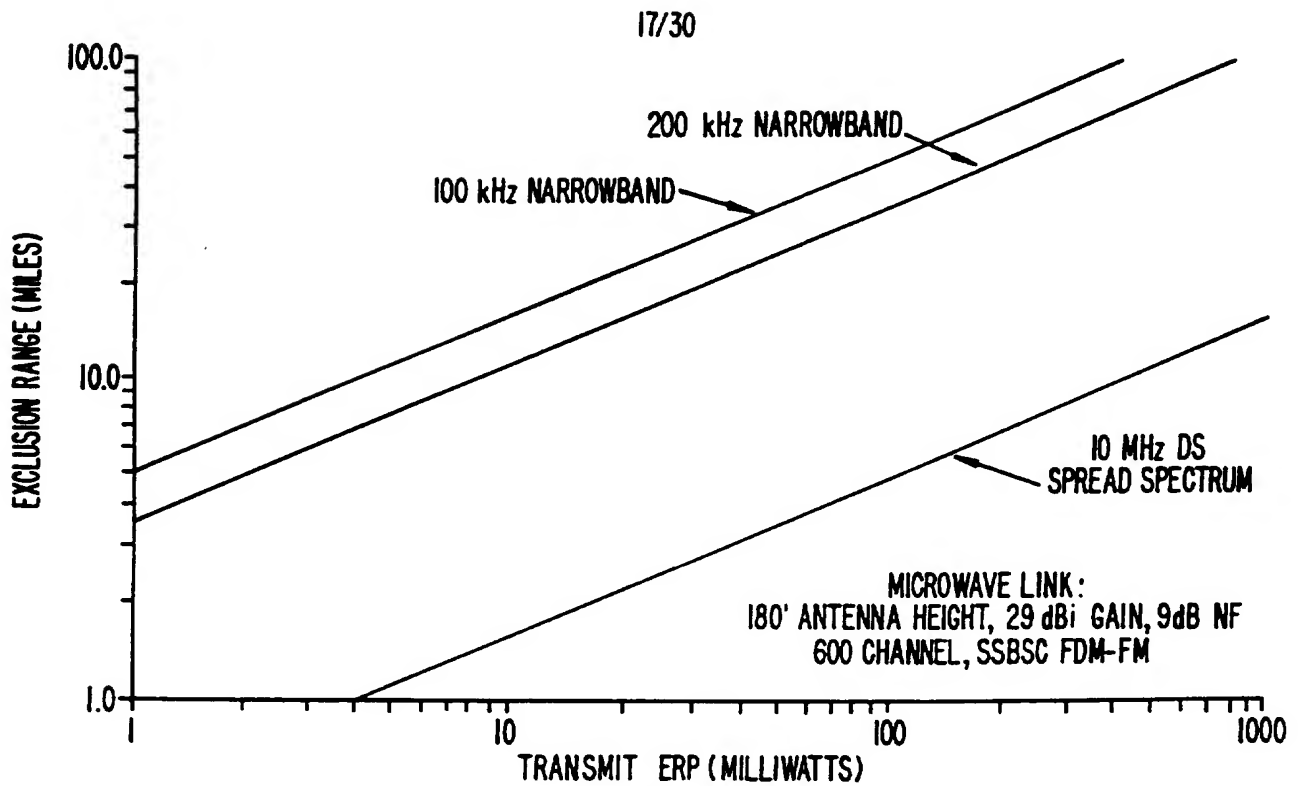


FIG. 18-4a.

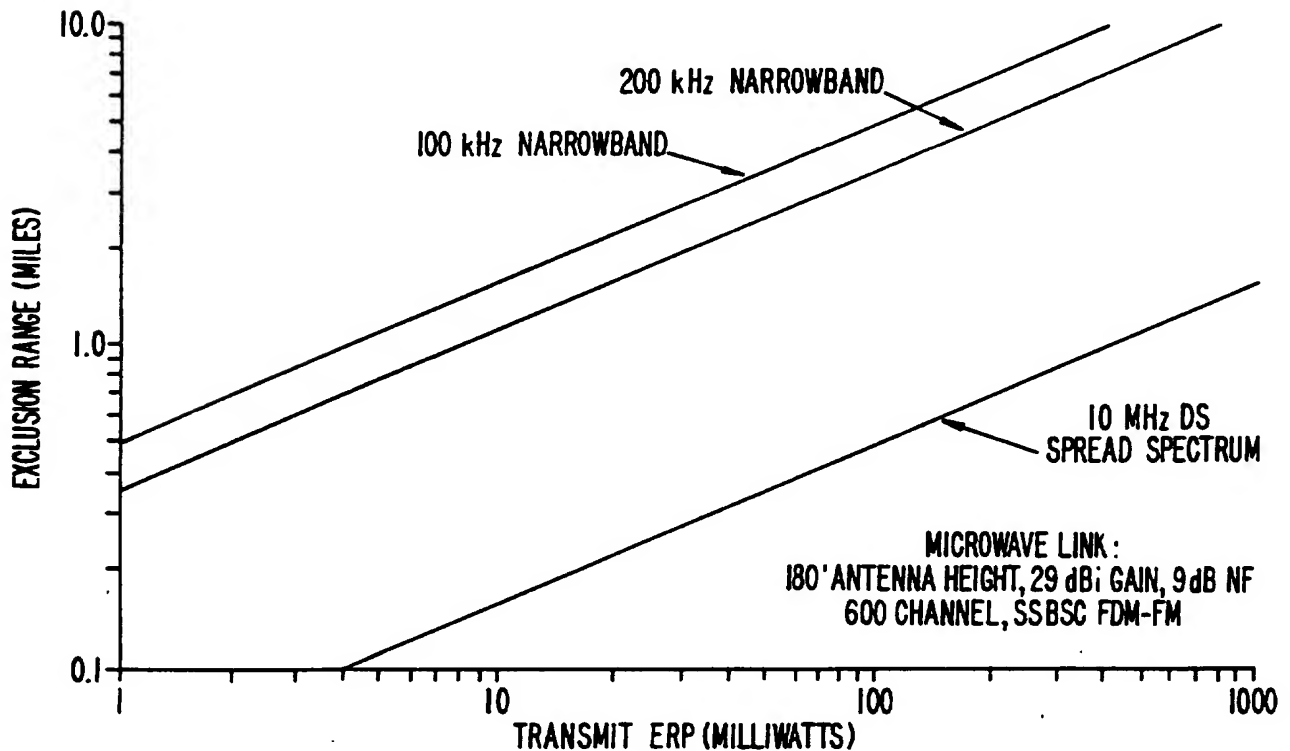
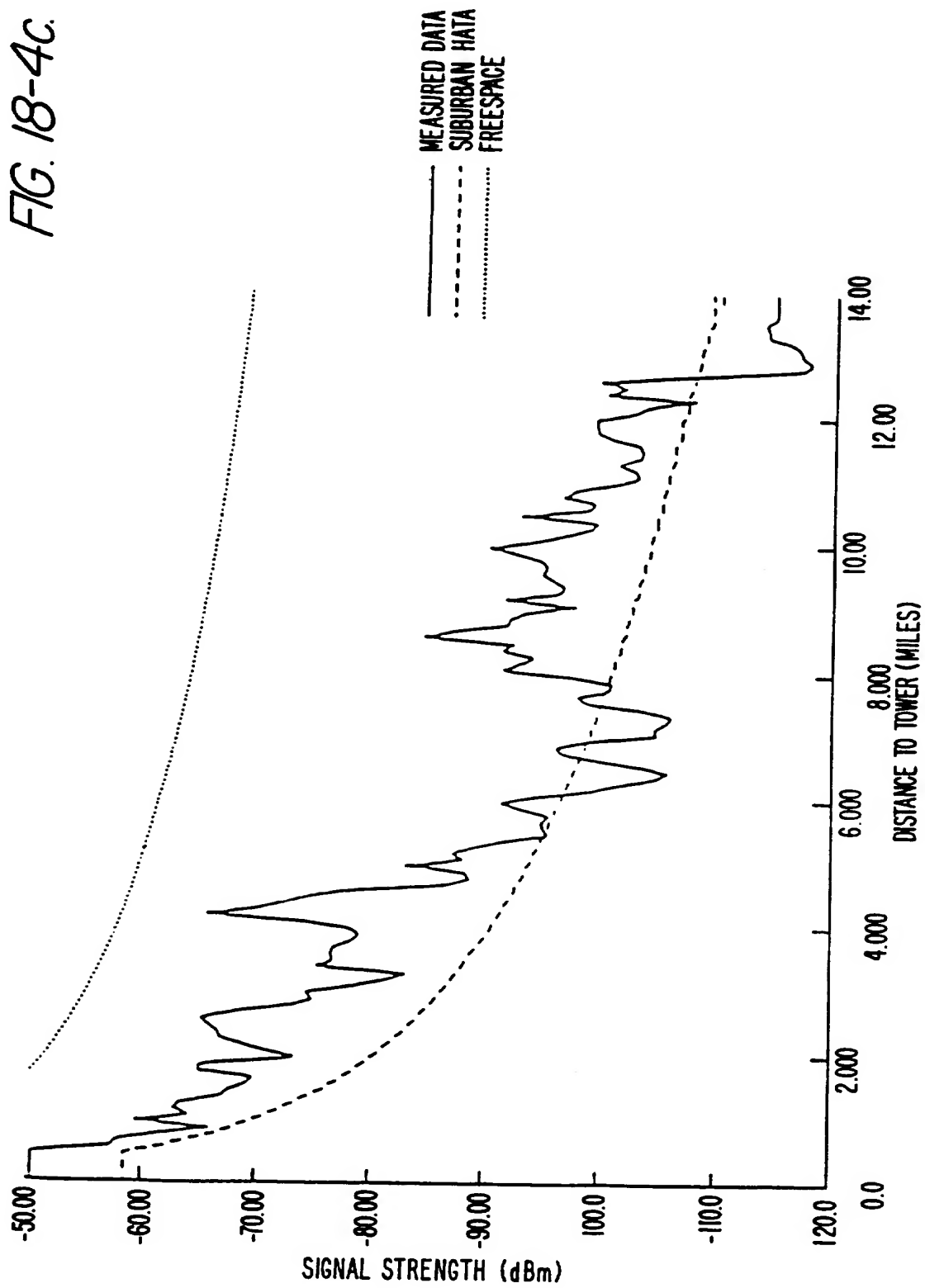


FIG. 18-4b.

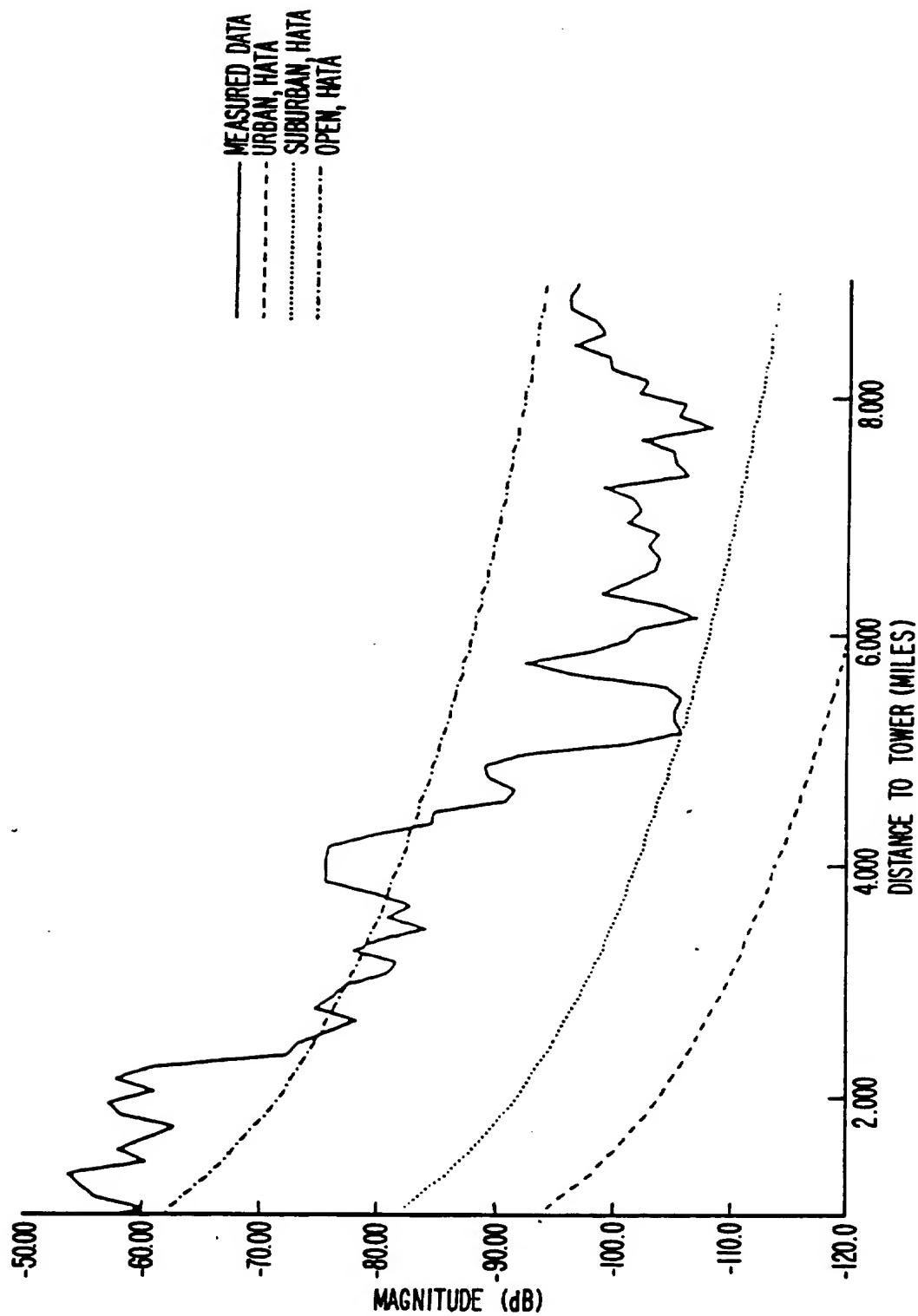
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FIG. 18-4c.



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FIG. 18-4d.



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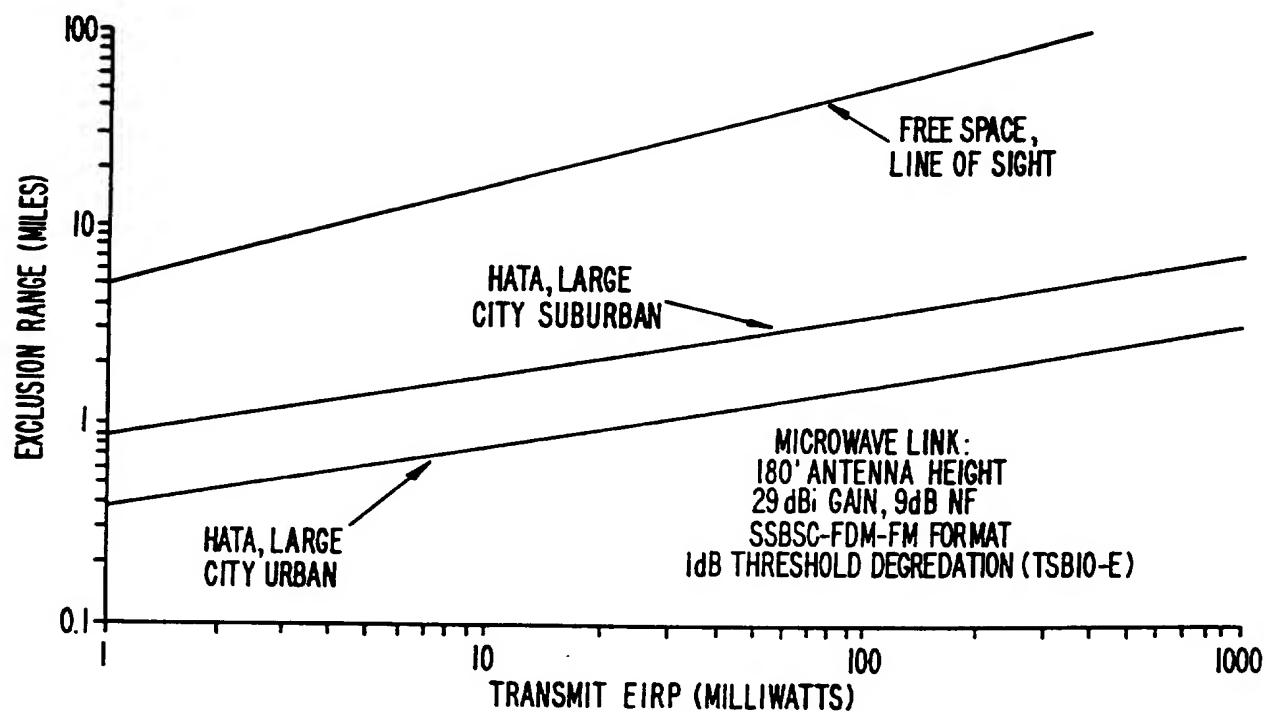


FIG. 18-5.

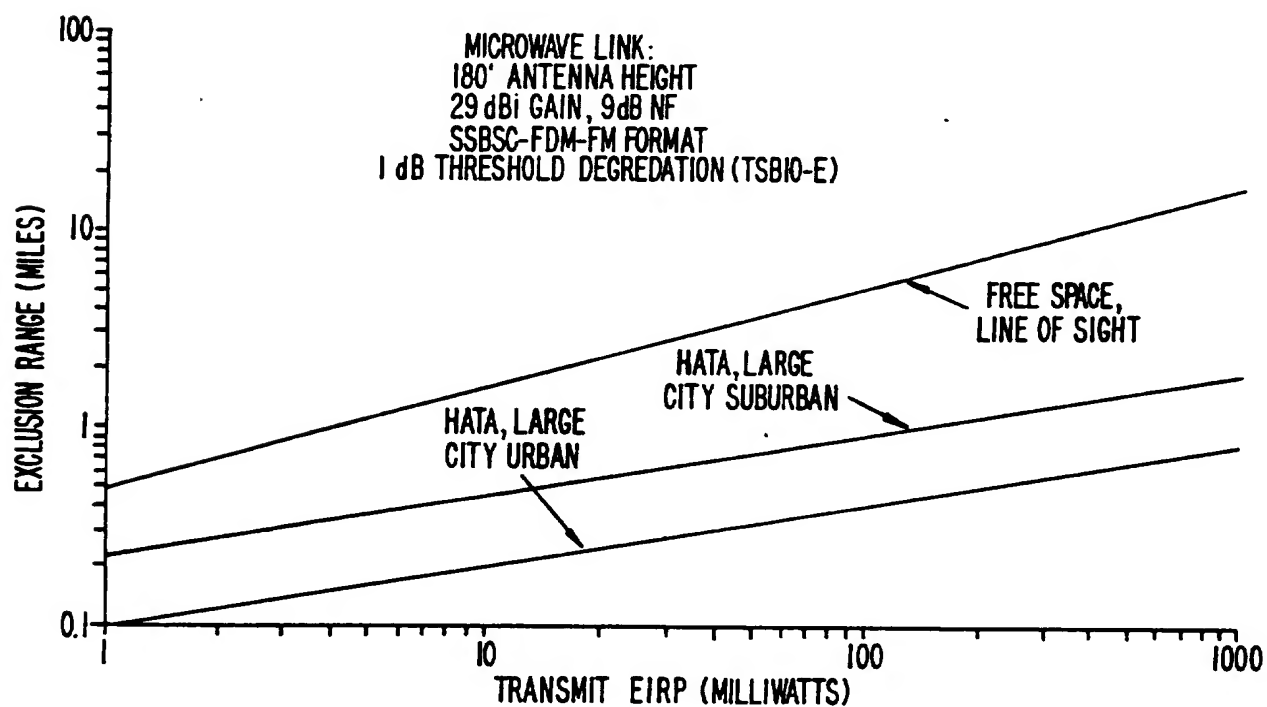


FIG. 18-6.

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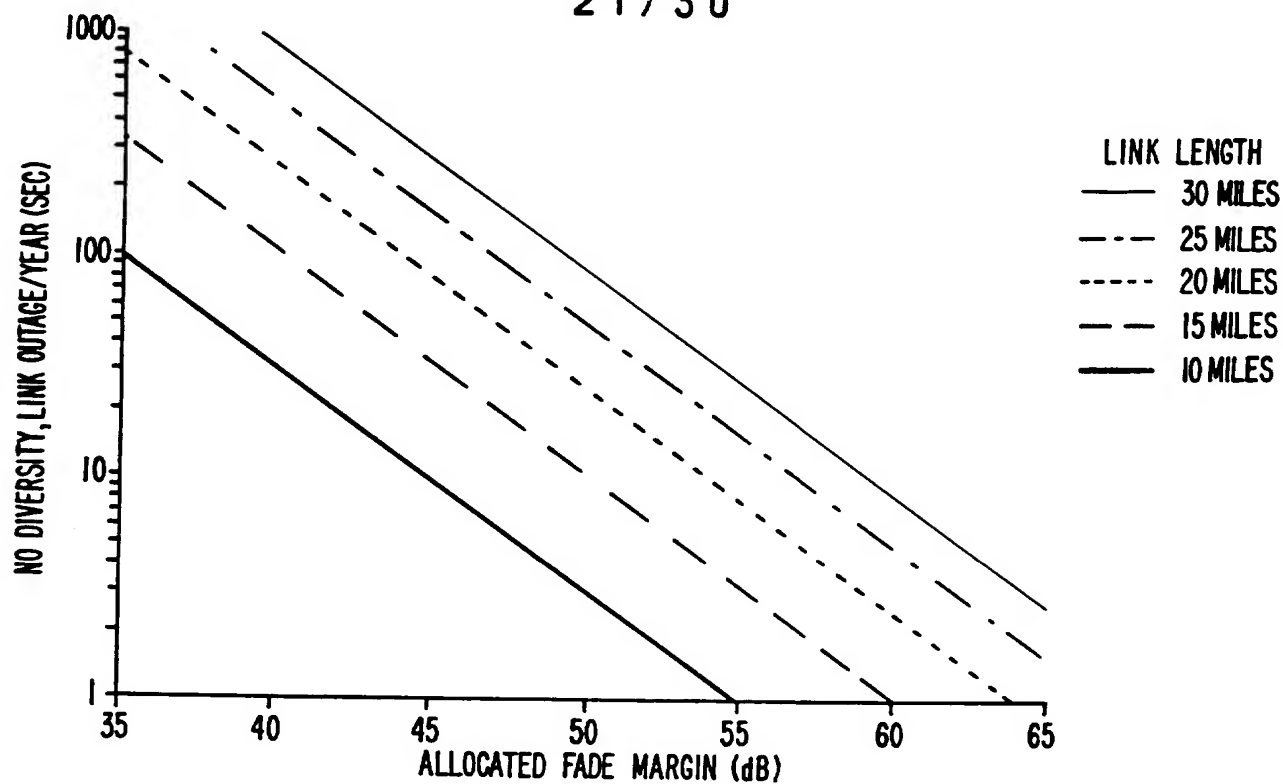


FIG. 18-7.

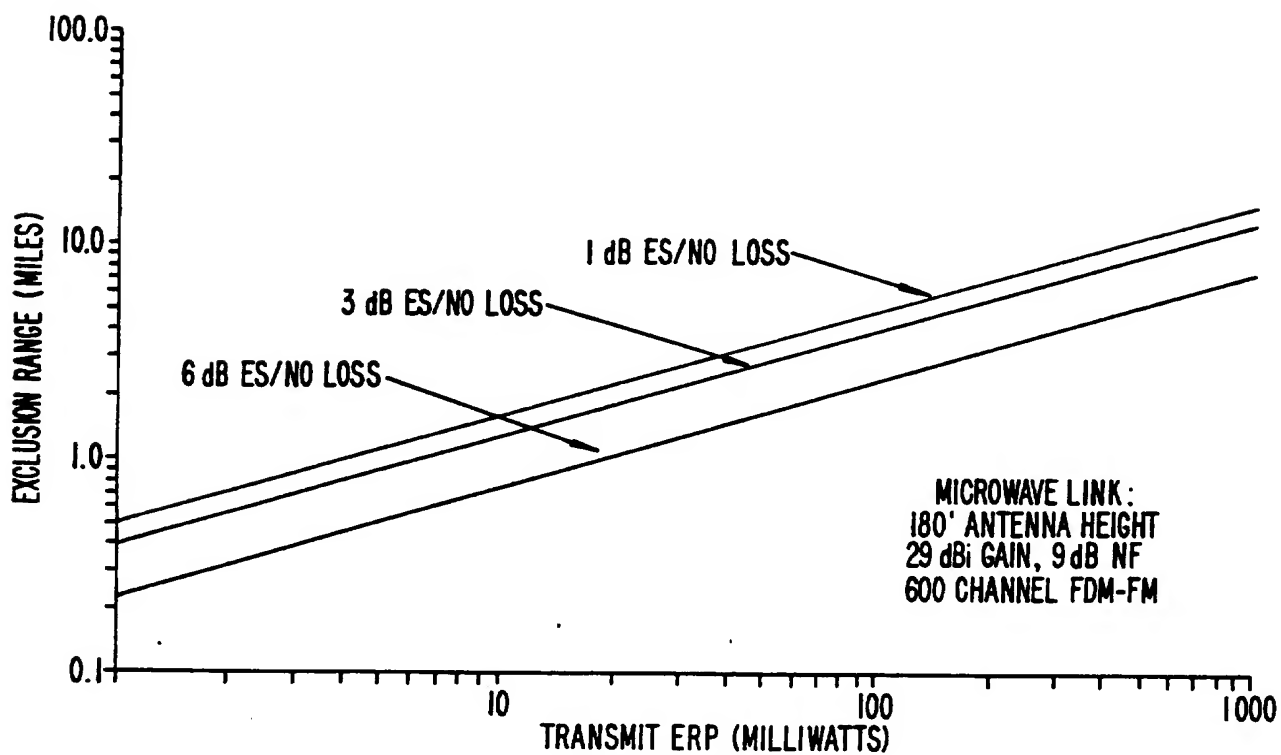


FIG. 18-8.

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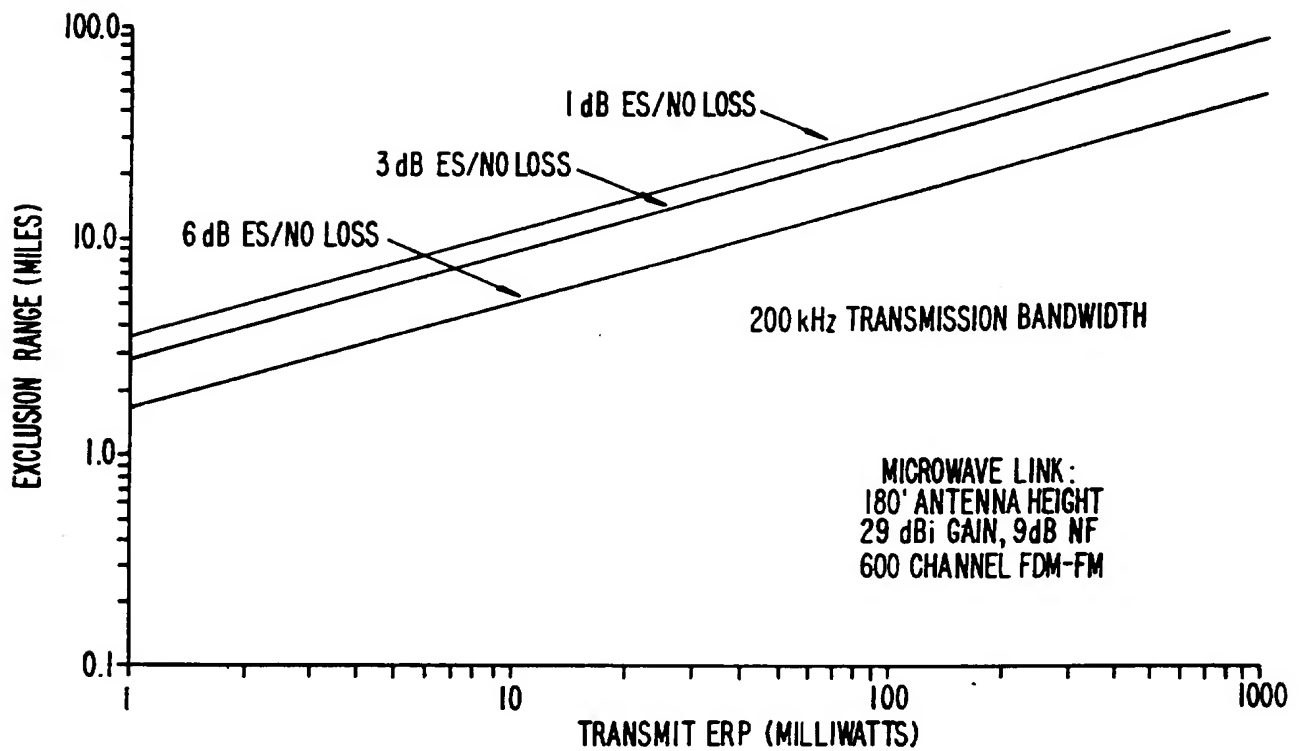


FIG. 18-9.

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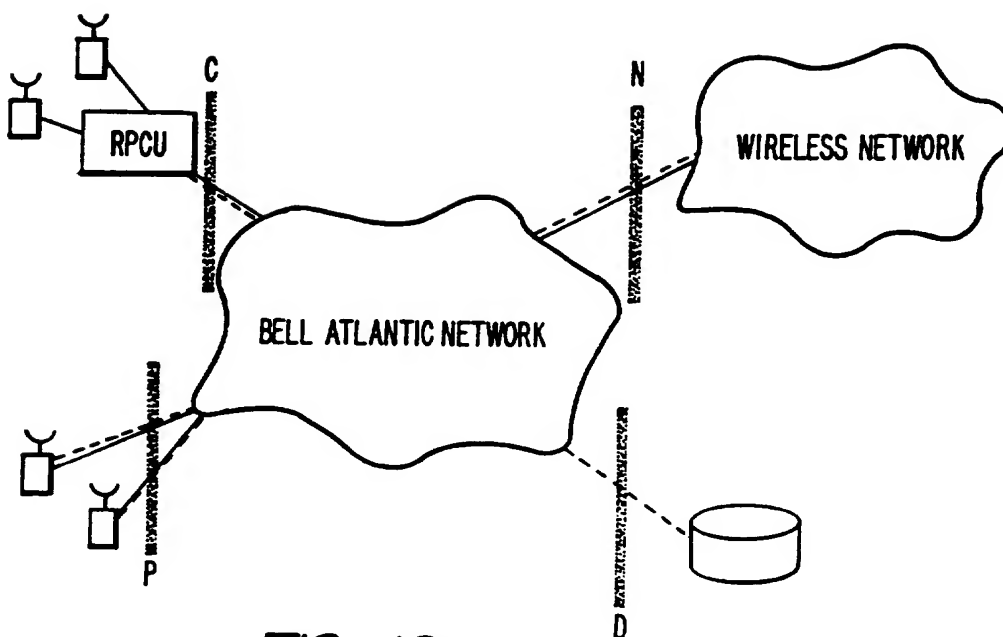


FIG. 19-1.

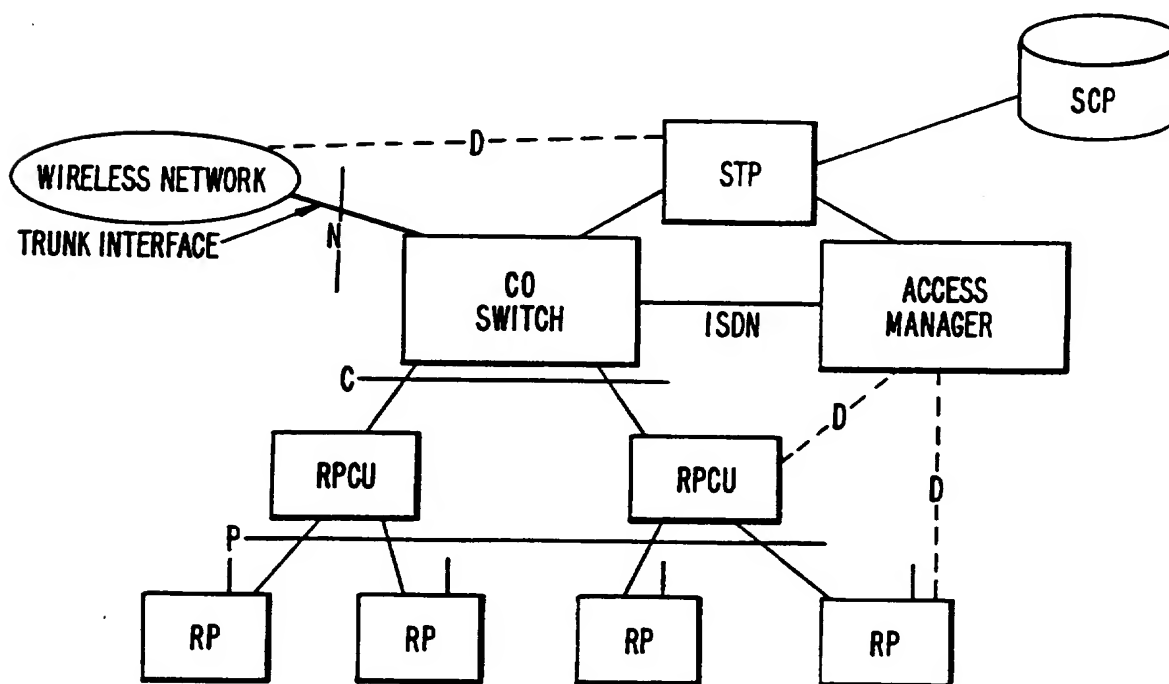


FIG. 19-2.

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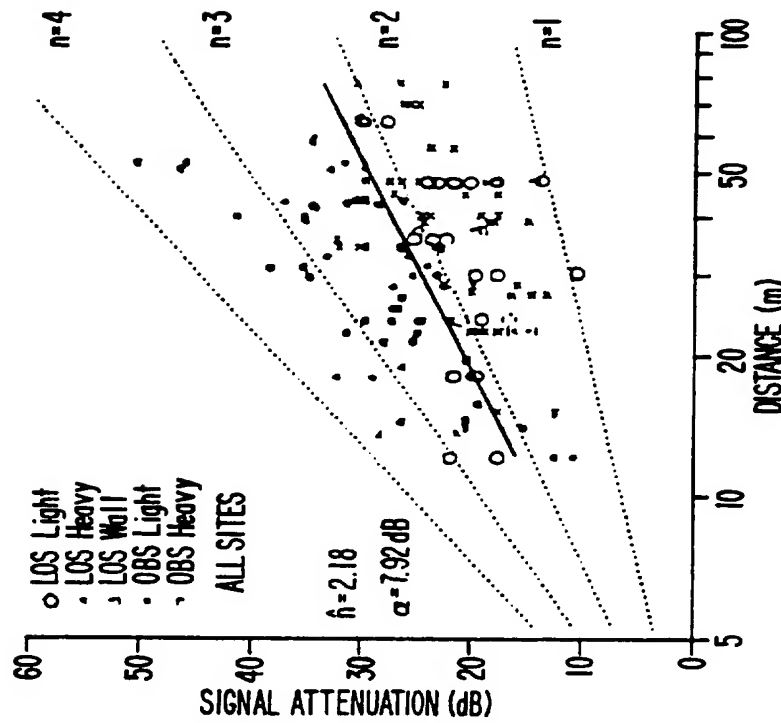


TABLE I. PATH LOSS EXPONENT AS A FUNCTION OF
FACTORY BUILDING (1,300 MHz)

FACTOR SITE	\hat{h}	α (dB)	NO. OF POINTS	CORR. COEF.
SITE B	2.39	10.20	33	.94
SITE C	1.89	5.55	41	.98
SITE D	2.43	7.94	34	.96
SITE E	2.12	8.03	18	.96
SITE F	1.92	4.79	17	.98

TABLE II. TABLE LOSS EXPONENT AS A FUNCTION
OF FACTORY TOPOGRAPHY (1,300 MHz)

FACTORY GEOGRAPHY	\hat{h}	α (dB)	NO. OF POINTS	CORR. COEF.
LOS light clutter	1.79	4.55	26	.98
LOS heavy clutter	1.79	4.42	43	.98
LOS along wall	1.49	3.9	8	.98
OBS light clutter	2.38	4.67	23	.99
OBS heavy clutter	2.81	8.09	43	.97

FIG. 20-1

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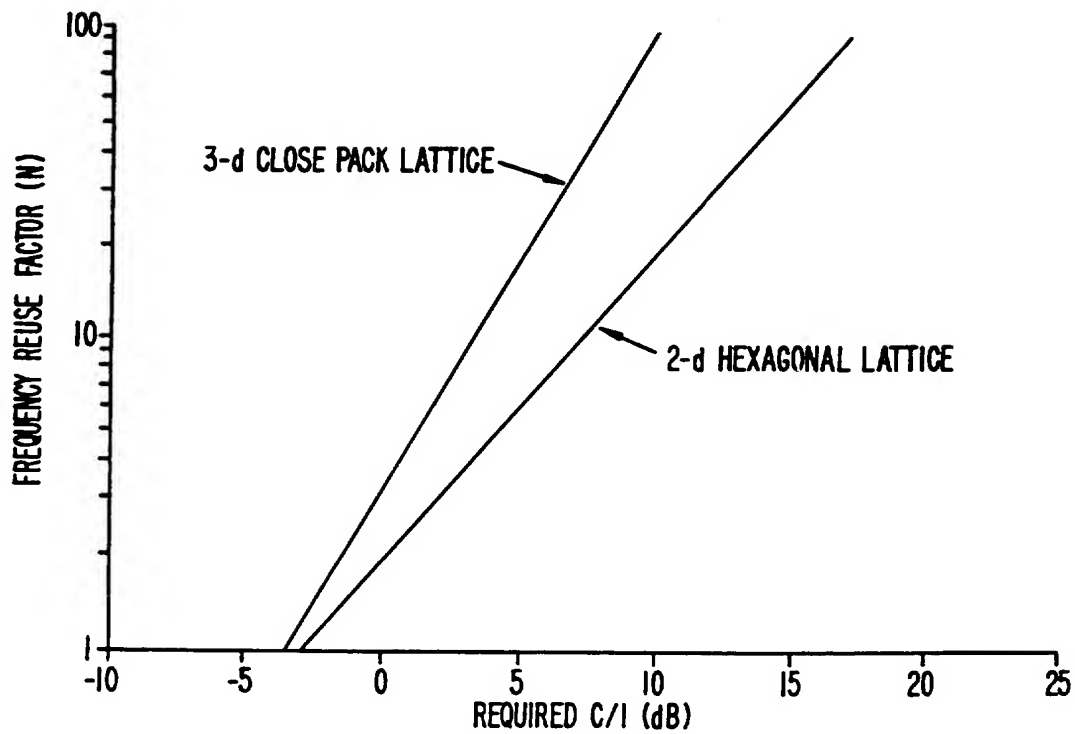


FIG. 20-2.

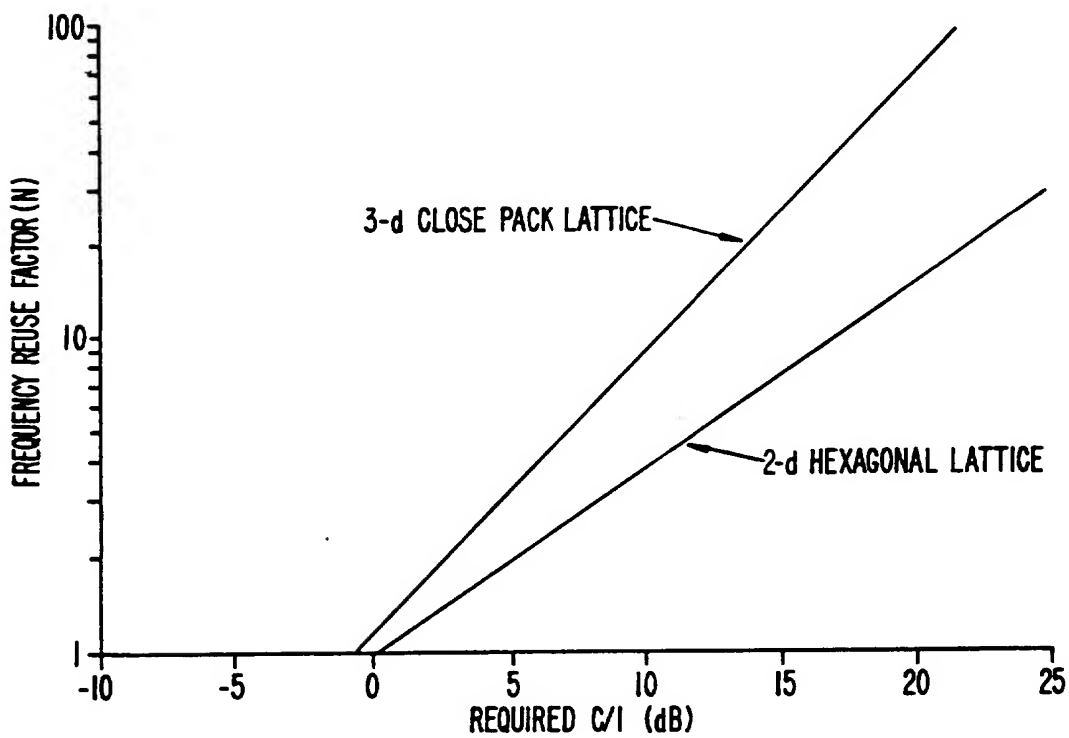
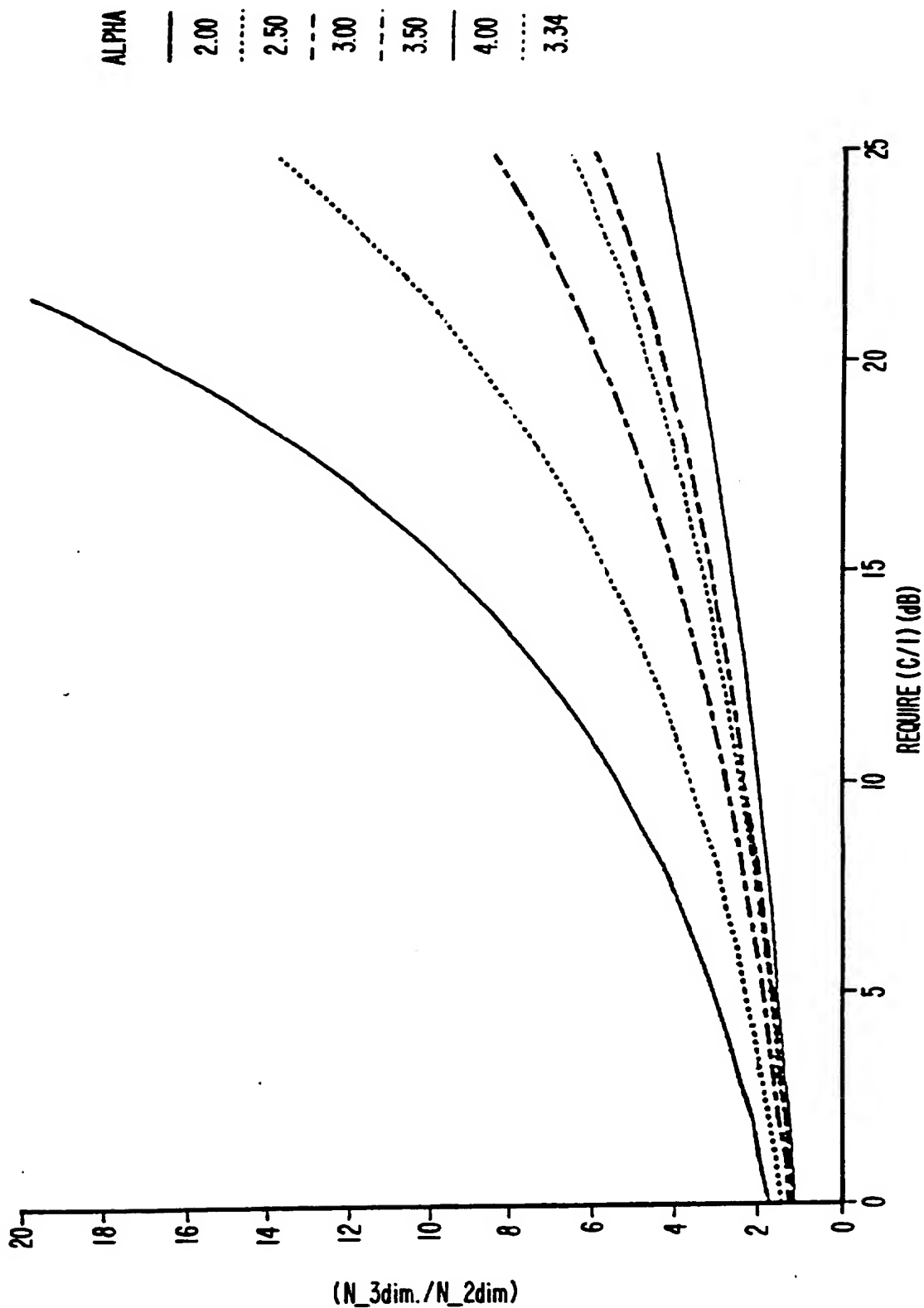


FIG. 20-3.

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FIG. 20-4.



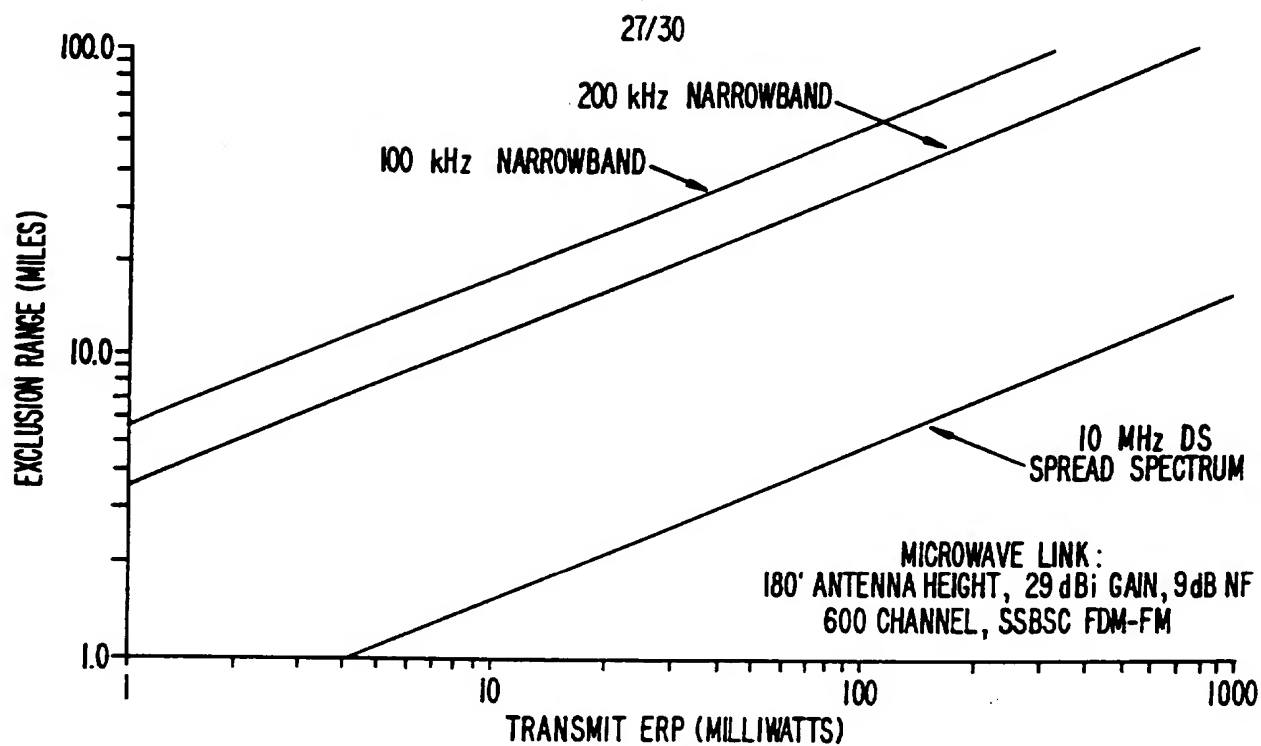


FIG. 21-1.

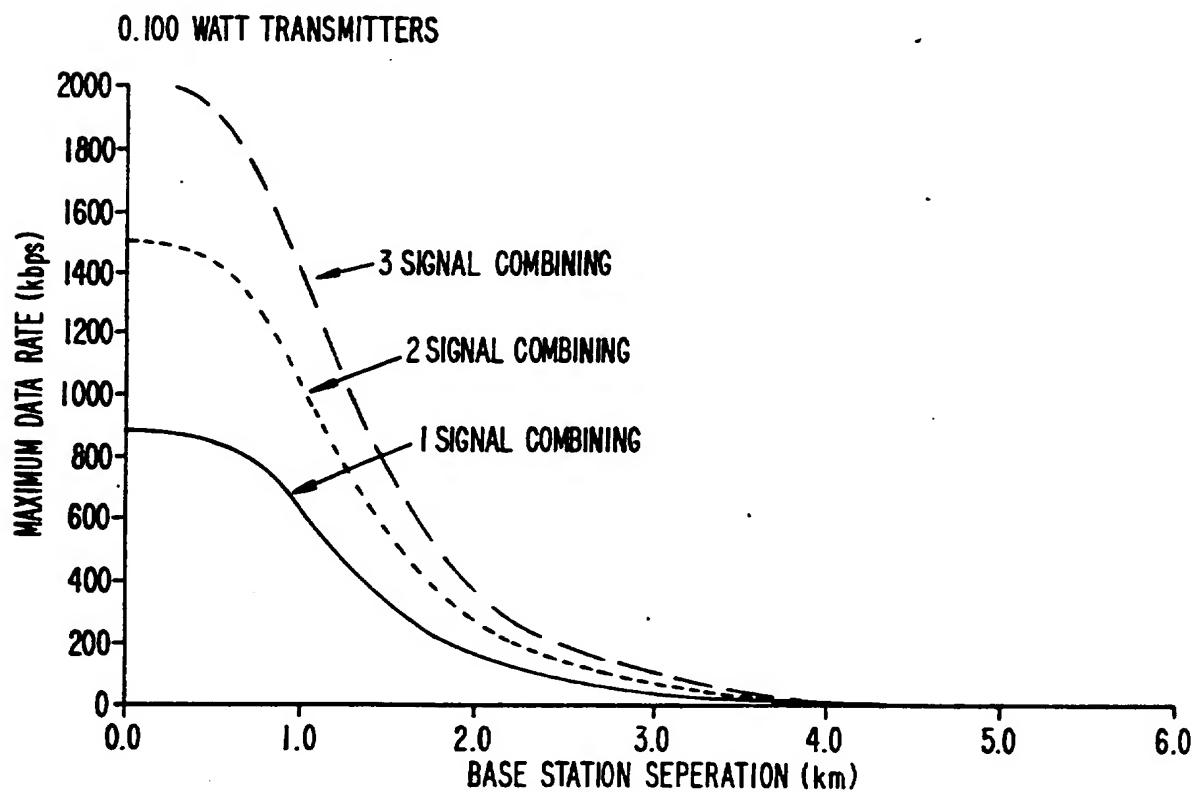


FIG. 21-3.

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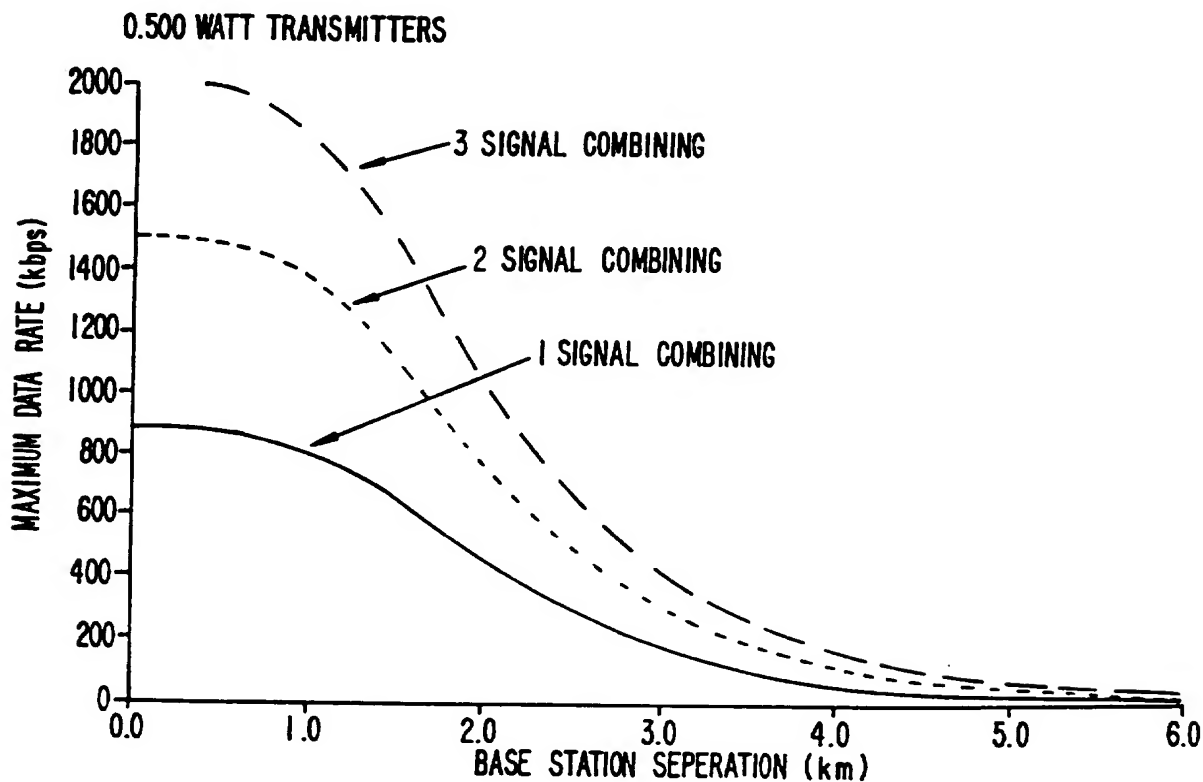


FIG. 21-4.

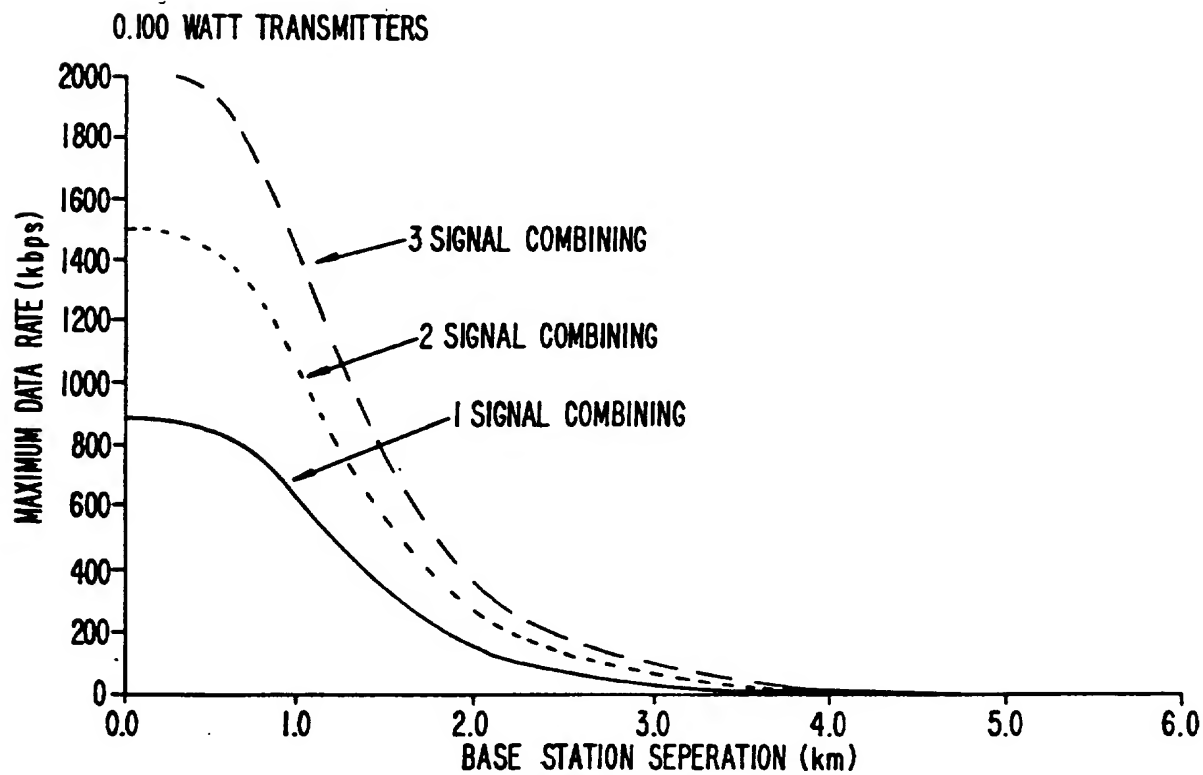


FIG. 21-5.

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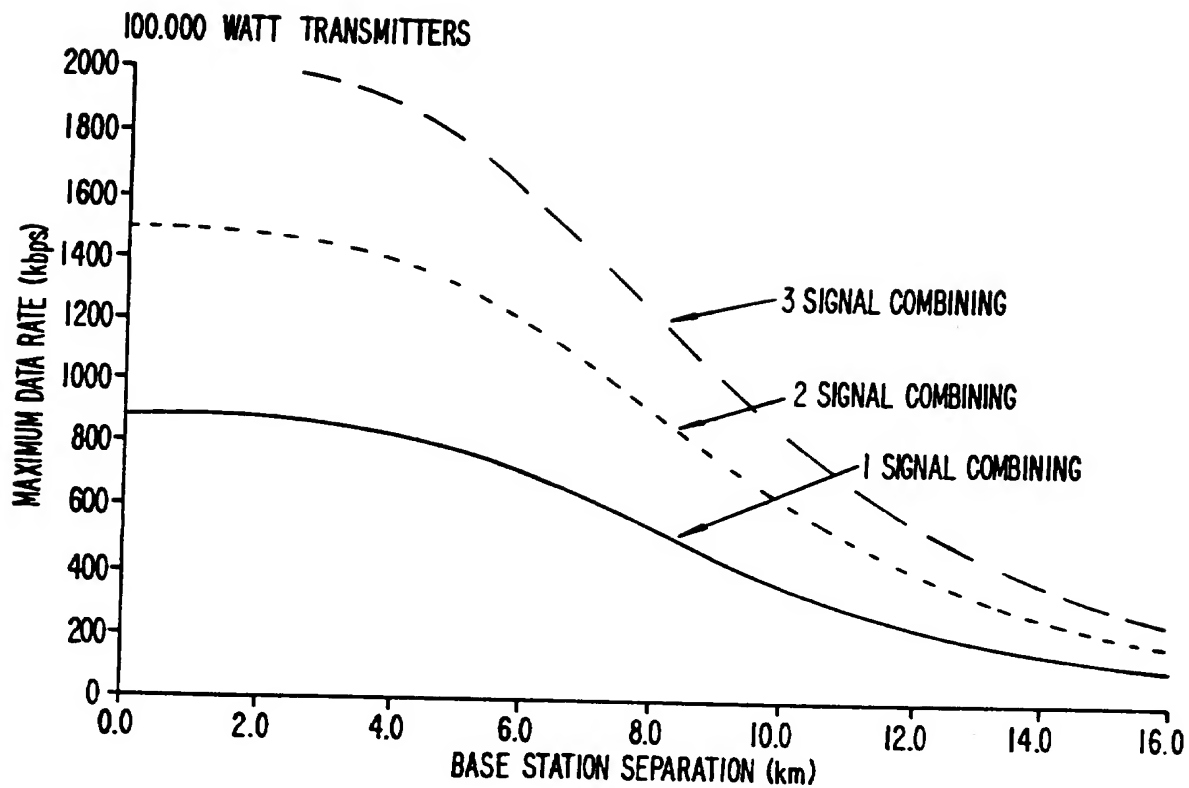
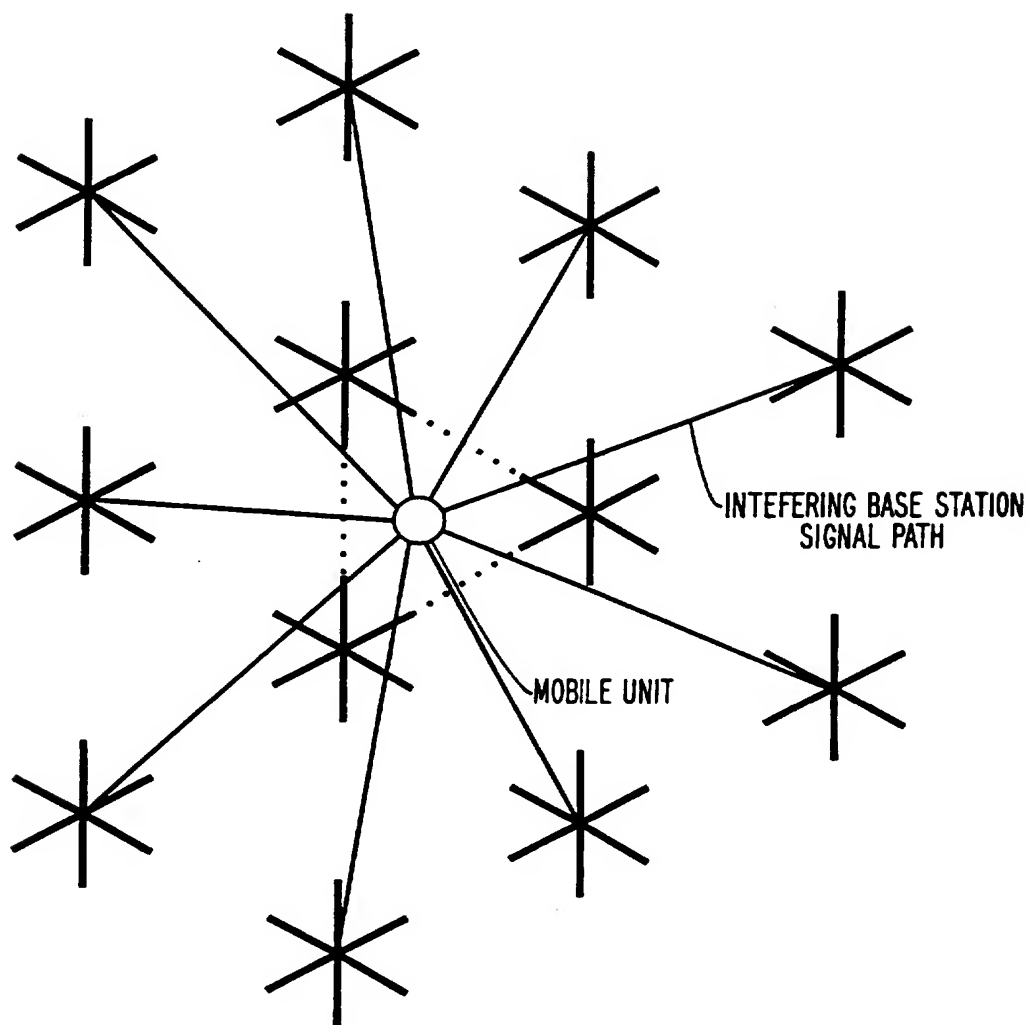


FIG. 21-6.

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FIG. 21-7.



* SIX SECTOR BASE STATION CELL SITE

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US95/10387

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04K 1/00; H04L 27/28; H04L 27/04, 27/06

US CL :375/200, 260, 295, 316; 455/73, 33.1; 379/60

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 375/200, 260, 295, 316,344; 455/59,61,33.4,73,76, 33.1; 379/59,60; 332/117,119,151; 329/315, 316, 347, 348

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS: (spread spectrum and narrow band), (multiple modulat? or plurality(2w)modulat?), (sub(1w)band or subband or multi band), (multi mode# or multimode#)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,P	US, A, 5,438,329 (Gastouniotis et al) 01 August 1995, see figures 1 and 2, and columns 3,4 and 6-7.	1-24
Y	US, A 4,797,677 (MacDoran et al) 10 January 1989, see figure 3.	25-38

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☐

See patent family annex.

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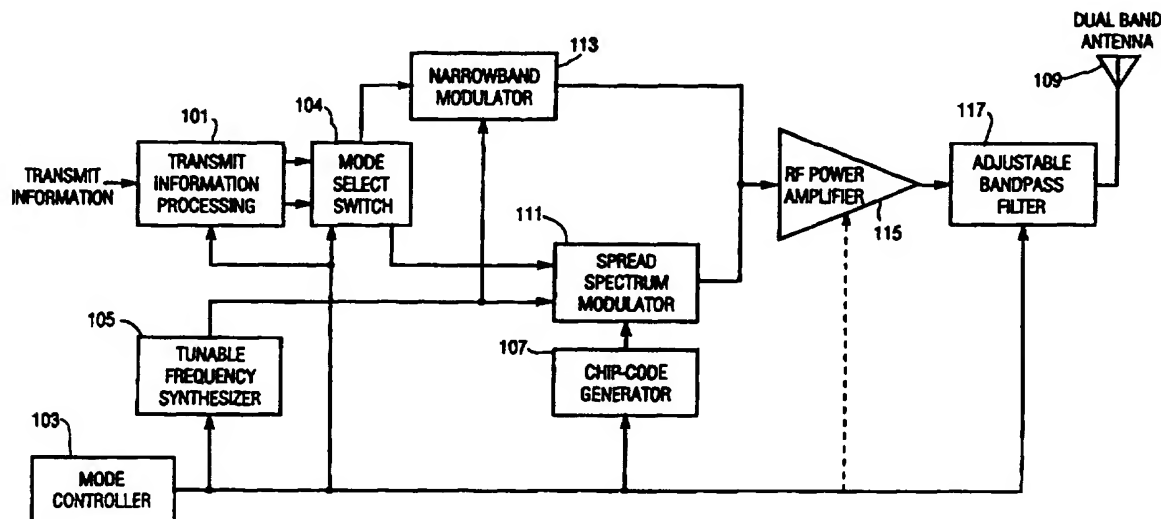
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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : H04K 1/00, H04L 27/28, 27/04, 27/06		A1	(11) International Publication Number: WO 96/06490
(21) International Application Number: PCT/US95/10387		(43) International Publication Date: 29 February 1996 (29.02.96)	
(22) International Filing Date: 15 August 1995 (15.08.95)		(74) Agents: HEMMINGER, Steven, D. et al.; Lyon & Lyon, Suite 4700, 633 West Fifth Street, Los Angeles, CA 90071-2066 (US).	
(30) Priority Data: 08/293,671 18 August 1994 (18.08.94) US PCT/US94/12464 31 October 1994 (31.10.94) WO (34) Countries for which the regional or international application was filed: US et al. 08/482,292 7 June 1995 (07.06.95) US 08/483,514 7 June 1995 (07.06.95) US 08/485,987 7 June 1995 (07.06.95) US		(81) Designated States: CA, JP, KR, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).	
(71) Applicant (for all designated States except US): OMNIPOINT CORPORATION [US/US]; 1365 Garden of the Gods Road, Colorado Springs, CO 80907 (US).		Published With international search report.	
(72) Inventors; and (75) Inventors/Applicants (for US only): SMITH, Douglas, G. [US/US]; 1200 North Veitch Street, Arlington, VA 22201 (US). DIXON, Robert, C. [US/US]; 14717 Perry Park Road, Palmer Lake, CO 80133 (US). VANDERPOOL, Jeffrey, S. [US/US]; 1856 Oak Hills Drive, Colorado Springs, CO 80919 (US).			

(54) Title: MULTI-BAND, MULTI-MODE SPREAD-SPECTRUM COMMUNICATION SYSTEM



(57) Abstract

A technique for spread-spectrum communication (figs. 1, 3, 12, 13 and 14) which uses more than one mode and more than one frequency band. Selectable modes include narrowband mode and spread-spectrum mode, or cellular mode and microcellular mode. A mode select switch (104) selects between a narrowband modulator (113) and a spread spectrum modulator (111). Selectable frequency bands include both licensed and unlicensed frequency bands, particularly frequency bands including the 902-928 MHz, 1850-1990 MHz, and 2.4-2.4835 GHz frequency bands (figs. 8, 9 and 10). Spread-spectrum communication channels are 10 MHz or less in width. The frequency band onto which spread-spectrum signals are encoded may be changed upon a change in environment or other control trigger, such as establishment or deestablishment of communication with private access network. A multi-band transmitter (fig. 12) comprises a single frequency source (606) (e.g., a local oscillator), coupled to a selectable band pass filter (619, 620). A multi-band receiver (fig. 14) capable of monitoring one or more frequency bands comprises a bank of bandpass filters (714, 715) and a demodulator comprising a single frequency synthesizer and a frequency source (721).

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